BIRLA CENTRAL LIBRARY
PILANI [RAJASTHAN]

Class No. 621.7

Book No. A85w V-5

Accession No. 59469

Acc. No 59469

ISSUE LABEL

Not later then the latest date stamped below.

29 [illegible] 7[illegible]

[illegible]

18 Apr [illegible]

WORKSHOP PRACTICE

VOLUME V

VOLUME V

DROP AND MACHINE FORGING

BY

R. H. BRIGGS, M.S.E., A.M.I.MECH.E.,
A.M.I.MIN.E.

AND

J. D. STRACHAN

DIE-MAKING, PRESS WORK AND STAMPING

BY

LEONARD BRAME

PRACTICAL BLACKSMITHING

BY

W. EMERSON, M.I.W.E.

WELDING

BY

W. HEIGH

WORKSHOP PRACTICE

A PRACTICAL WORK FOR THE DRAUGHTSMAN.
THE MECHANIC, THE PATTERN-MAKER, AND
THE FOUNDRYMAN

SECOND EDITION

EDITED BY
WILLIAM H. ATHERTON
M.Sc., M.I.Mech.E.

VOLUME V

LONDON
SIR ISAAC PITMAN & SONS, LTD.
1944

SIR ISAAC PITMAN & SONS, LTD
PITMAN HOUSE, PARKER STREET, KINGSWAY, LONDON, W.C.2
THE PITMAN PRESS, BATH
PITMAN HOUSE, LITTLE COLLINS STREET, MELBOURNE
UNITEERS BUILDING, RIVER VALLEY ROAD, SINGAPORE
27 BECKETTS BUILDINGS, PRESIDENT STREET, JOHANNESBURG

ASSOCIATED COMPANIES
PITMAN PUBLISHING CORPORATION
2 WEST 45TH STREET, NEW YORK
205 WEST MONROE STREET, CHICAGO
SIR ISAAC PITMAN & SONS (CANADA), LTD
(INCORPORATING THE COMMERCIAL TEXT BOOK COMPANY)
PITMAN HOUSE, 381–383 CHURCH STREET, TORONTO

BOOK
PRODUCTION
WAR ECONOMY
STANDARD

THE PAPER AND BINDING OF
THIS BOOK CONFORM TO THE
AUTHORIZED ECONOMY STANDARDS

MADE IN GREAT BRITAIN AT THE PITMAN PRESS, BATH
D4—(T 5517) v

PREFACE

Drop forging, Die-making, Stamping, Blacksmithing, and Welding are all inter-related and have much in common. They are the means for shaping and manipulating metals without the necessity for pattern-making and foundrywork, which subjects are dealt with in Volume II of this publication. Only a limited number of objects, however, lend themselves to forgings. The majority of complicated structures require castings.

The demand for forgings instead of castings is now very great, and it may readily be understood when one realizes the many inherent advantages that forgings possess over castings. Forgings—and particularly drop forgings—are entirely free from those obnoxious imperfections such as blow-holes and concealed cracks, and, in addition, they offer a peculiarly powerful resistance to heavy impact shocks. Moreover, it should be remembered that drop forging speeds up production very greatly with no loss in accuracy or quality.

In the section on Drop and Machine Forging by Mr. R. H. Briggs and Mr. J. D. Strachan, drop forging is considered in detail, and the reader will find much very practical information on the handling of modern drop forging plant, which is described and illustrated, and the preparation and use of dies. American and English methods are reviewed and compared.

Immediately following this section is one on Die-making, which is, of course, intimately bound up with Drop Forging and Press Work. Dies are considered in drop forging to some extent, but the information given is greatly amplified in Section XXI, where the ground is covered by Mr. Brame, who has had considerable experience in this work.

Then follows an illuminating section on Blacksmithing by Mr. W. Emerson, who himself is in charge of certain well-known forges, and is responsible for the production of some very fine examples of this still flourishing and highly skilled craft. In the later portion of his contribution he touches on the question of ornamental work, which is where the blacksmith can give full expression to his manipulative skill and artistic ability, and can thus command a very extensive market for his goods.

To conclude the volume, there is a newly-written section on Welding by Mr. W. Heigh. In this both the electric arc and the gas processes are treated in detail, and valuable notes are given on the properties and behaviour of various metals under practical welding conditions.

CONTENTS OF VOL. V

PAGE

PREFACE v

SECTION XX

DROP AND MACHINE FORGING 3

Introduction—Early progress—Drop stamps—Power lift—Steam lifter—Friction lifter—Board hammers — Steam hammers — Foundations — Heading or forging machine—Quality of upset forgings—Forging press—Shop methods—Dies for drop forging—Uses of the fin—Oversize fin—Size of stock—Long thin-bodied stampings—Bending the stock—Forked stampings—Furnaces—Removing the fin—Cleaning, heat treatment, and inspection—Brass stampings—General equipment

SECTION XXI

DIE-MAKING, PRESS WORK AND STAMPING . 79

Introduction to the workshop—Precision instruments—Blue prints—Making the tool—Final assembly—Alternative methods of lay-out—Determining the blank sizes—Spring pad bending tool—Various types of special tools—Bending and forming—Blanking and piercing tool—Bolster and spigot plate—Die—Main punch—Stripper—Side stop—Final assembly work—Blank tool with spring stripper—Die lay-out—Sectional dies—Lay-out of follow-on tool—Side piercing tool—Blanking formed fittings—Open dies with spring strippers—Draw plate tool—Application of drilling machine—Dies for candle shade holder—Production of toy train wheel—Embossing die—Piercing bush—Embossing punch—Large tools—Domestic bowls—Stove canopies

PAGE

SECTION XXII

PRACTICAL BLACKSMITHING . . 157

Importance of the blacksmith—The smithy—Blacksmith's appliances—Blacksmith's tools—Forging smith's tools—Hardening and tempering—Drawing and tapering—Upsetting, scarfing, welding—Bending—Effect of tools on grain in iron—Forging of hinges—Methods of determining length of material in rings—Forging eyes—Fork ends—Bending and welding angle iron—Power hammers—Ornamental ironwork

SECTION XXIII

WELDING 231

Heat and temperature—Scale and overheating in certain plastic processes—Problems in fusion processes—Distortion, residual stress and chilling—Success of modern welding processes—Arc welding processes—Metallic arc welding—Welders' tools—Welding machines—Direct and alternating current—Welding cables—Faults in the welder's circuit—Factors in practice—Welding positions—Scope of the process—Carbon arc welding—Atomic hydrogen welding—Gas processes of fusion welding—Oxygen—Acetylene—The welding flame—Plant lay-out—Joints—Applications—Other welding flames—Gas cutting—Thermit fusion welding—Bronze welding—Welding various metals—General conclusion—Appendix

APPENDIX: Safety Precautions and Regulations . 337

INDEX 343

INSETS

facing page

Various Forms of Blacksmith's Tongs 174
Some Fullering Operations 203
The Metallic Arc in Welding 247

SECTION XX

DROP AND MACHINE FORGING

BY

R. H. BRIGGS, M.S.E., A.M.I.MECH.E.,
A.M.I.MIN.E.

AND

J. D. STRACHAN

SECTION XX

DROP AND MACHINE FORGING

INTRODUCTION

Drop forging and drop stamping is the method of shaping hot iron, steel, or other metal in dies by the heavy blow of a falling mass of metal, the top half of the die being fastened in the falling mass. This operation is less simple than at first sight it may appear to be, and the machinery and methods in use have been evolved by the thoughtful effort of many brains combined with years of practical experience, while modern practice has been specially affected by the need for mass production.

The principle of drop forging in embryo could be seen in the tools of the old blacksmith's shop. The swages, boss-forming tools, and more especially the spring swages, in which both top and bottom dies are present, and the sledge hammer, which took the place of the drop stamp tup, bear at least some resemblance to the modern drop-stamping machine. These the old smith used when he had to make a number of articles of the same size. Fig. 1 shows a typical blacksmith's spring swage.

EARLY PROGRESS

An improvement on the old smith's method was the foot oliver or " olifer," which has been for years in universal use in the Midland Black Country districts, and even now is in action in scores of small works for making nails, rivets, frost studs, horseshoes, and all kinds of odd work. This consists of a heavy hammer head with a shaft fastened at right angles to an axle, each end of which is pivoted in an upright timber baulk. The hammer is kept raised by a spring. In the old type it was a sapling or branch of a tree, with one end fastened in the roof and connected to the shaft of the hammer with a chain. The axle to which the shaft is fastened has a lever connected with a rod to a treadle, so that when the workman presses the treadle down the hammer head swings down, and when he releases the treadle the spring raises it again. The hammer strikes on an anvil block, and one of the tools or dies is fitted in the hammer head and one in the anvil. Usually these are held by taper shanks. The primitive method usually employed in making the tools was that of fixing the blank tools in place hot and then striking a number of heavy blows on to a hard steel master pattern of the forging to be made. The tools were smoothed over with hand tools, and were then hardened.

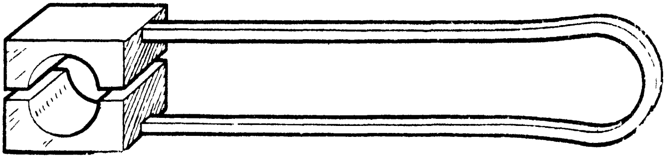


FIG. 1. BLACKSMITH'S SPRING SWAGE

In the case of the oliver, the blow is struck in the form of an arc of a circle instead of falling vertically, and consequently as the tools wear, or if the anvil moves in its foundation, or the tools are not set exactly in the same position each time, the forging will not be true, as the tools do not meet truly face to face. To overcome this difficulty an improved type of oliver has been designed with two bars to form the helve or shaft, each bar working on a separate axis, one above the other, and the ends of the bars working on pins in the hammer head. This forms a type of parallel motion, which keeps the face of the hammer tool always horizontal in spite of the arc through which it moves.

DROP STAMPS

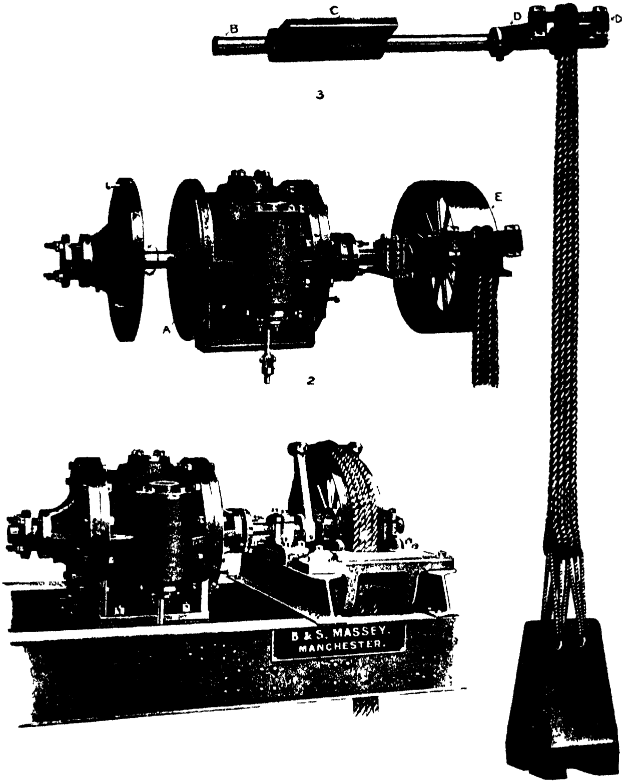
The true drop stamp, however, is a heavy weight, usually called a tup, which can travel in a vertical line between two or more guides and which, after being raised to a certain height, is allowed to fall, its own weight giving the necessary energy to the blow. It is, of course, necessary to receive the blow on an anvil and for guides to be fastened to this anvil, so that the blow must always fall in the same place. Both anvil and tup have means provided for holding the bottom and top half of the dies respectively, and some method of lifting the tup is also arranged.

THE POWER LIFT

To enable heavier tups to be used, the friction of a strap or belt on a pulley was brought into action. The grooved pulley soon gave way to a flat-faced one, and this was mounted on a shaft driven by power. The stamp tup was fastened to a belt or strap, which passed over the pulley, and when the free end of the belt was pulled the belt was held on to the moving pulley and the friction raised the tup without much strain on the workman. The wider the pulley and belt the heavier the tup which could be raised.

In this type of stamp a swinging catch is often provided on one or both of the guides on which the tup can be rested, with the tools well apart so that the tools can be fixed, inspected, and cleaned. The top half of the dies, when a pair of dies is used, is usually fastened in by a dovetail and ket. The anvil, as a rule, has poppets and fixing screws, so that the bottom die can be set to be true with the top one.

In the case of the heavier stamps, the wear on the belt or strap is great. Special kinds of woven hair or cotton belt have been found to give better results than leather. and there are firms who specialize in stamp belts. Flexible steel bands have been used instead of straps and combinations of straps and bands. As bigger and heavier stamps were designed, various devices to



(*B & S. Massey, Ltd.*)

Fig. 2. Steam Lifter

increase the friction on the lifting stroke were tried, but there is a limit to the weight of the friction strap-driven tup.

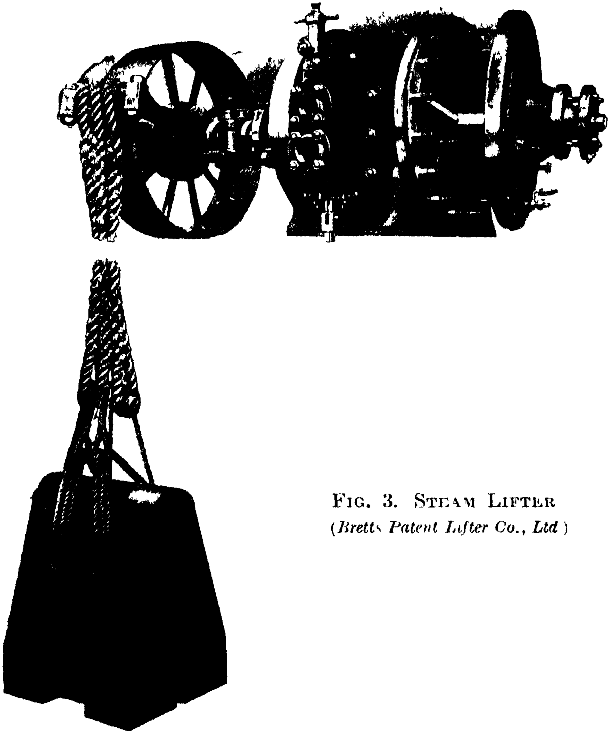


Fig. 3. Steam Lifter
(*Brett's Patent Lifter Co., Ltd.*)

In England, the use of steam drop stamps of the steam hammer type, with steam used to give greater effect to the blow, has not found very much favour with drop forgers. The blow this type of stamp gives is different from that which is given by a stamp in which the tup falls by gravity alone. The gravity fall has qualities of elasticity and rebound which are essential for the proper flow of metal in dies. At the same time, where steam is available, it forms a very convenient means of power for lifting the tup, and English drop stamp makers have evolved a type of steam lifter which enables the gravity fall blow to be used. and does not employ the piston rod.

STEAM LIFTER

The steam lifter consists essentially of a cylinder with two end covers with stuffing boxes, through which a shaft passes centrally through the cylinder. The shaft has a vane piston securely keyed to it. The vane piston can rotate on its shaft through about three-fourths of the internal circumference of the cylinder. the rest being blocked by a divisional segment. The piston has steamtight packing on each edge, consisting of phosphor bronze strips pressed out by springs, and the divisional segment has similar packing working against the shaft. Steam is admitted between the divisional segment and the piston, causing it to rotate, and so to rotate the shaft. The shaft is continued outside the cylinder, and is carried in bearings between which two lifting arms, securely keyed to the shaft, work. These arms are connected at their ends with a link to which the lifting rope or strap of the stamp is fixed, a loose pulley being mounted on the shaft between the arms on which the strap or rope rests. As the shaft is rotated by the piston the tup is raised ; when the steam is exhausted the tup falls. The admission and exhaust of the steam is regulated by a valve, so that any length of stroke can be given or the tup held up. Buffers are fixed to check the lifting arms at each end of their stroke.

The steam valve gear is designed to cut off before the full stroke is taken, so as to use the expansion of the steam and to form an air buffer to bring the piston to rest quickly at the top of full stroke. Very heavy stamps for large forgings have been made of this type, both by Bretts Patent Lifter Co., Ltd., and by B. & S. Massey, Ltd. (see Figs. 2–3).

THE FRICTION LIFTER

As it is not always convenient to use steam as the motive power for driving stamps (and there is still a demand for a stamp that will do heavy work, beyond the capacity of the stamp driven by the friction of the lifter strap on a driven pulley), the drop stamp engineers have perfected what may be termed a friction clutch type of stamp, usually termed friction lifters. There have been many attempts to apply the friction clutch to a drop stamp. the difficulty being to find some means of putting the clutch quickly out of operation and leave the tup free to fall when the blow is needed, and also to get such sensitive control of the friction that the tup can be held stationary in any position.

These difficulties have been overcome in the Brett patent,friction lifter in the following manner. A steel drum on which there are friction grooves is securely keyed to the driving shaft, and on each side of the drum two levers are mounted, these being free to turn on the shaft. A shackle is pivoted in the end of one lever and works in a jaw formed in the end of the other. This shackle has wedge-shaped friction blocks engaging in the grooves of the friction drum, but normally held clear of them by a spring. The end of the shackle can be pulled down by a cord to make the friction blocks grip in the grooves of the pulley. When this occurs the friction blocks are rotated with the drum, carrying the shackle with them. The lifting ropes or straps of the stamp are fixed to the shackle with a loose pulley mounted on the shaft to support them, so that as the shackle rotates the stamp is raised.

The cord which pulls the shackle down is coiled round a small winch or drum on the shaft, and when the end of the cord is pulled the friction of the cord on the winch gives the necessary power to put the friction clutch in operation, and the tup is raised. When the cord is released the friction blocks are released, and the tup drops freely. If, however, after the cord has been

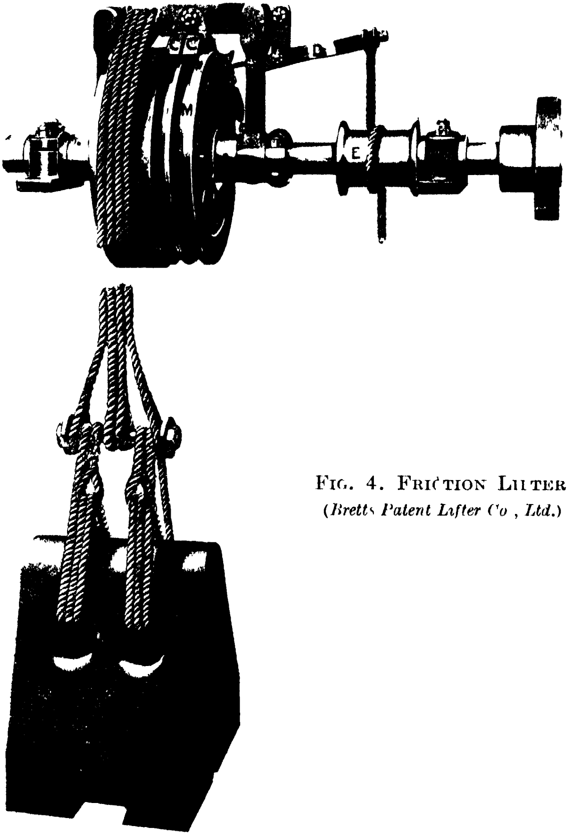


FIG. 4. FRICTION LIFTER
(*Brett's Patent Lifter Co., Ltd.*)

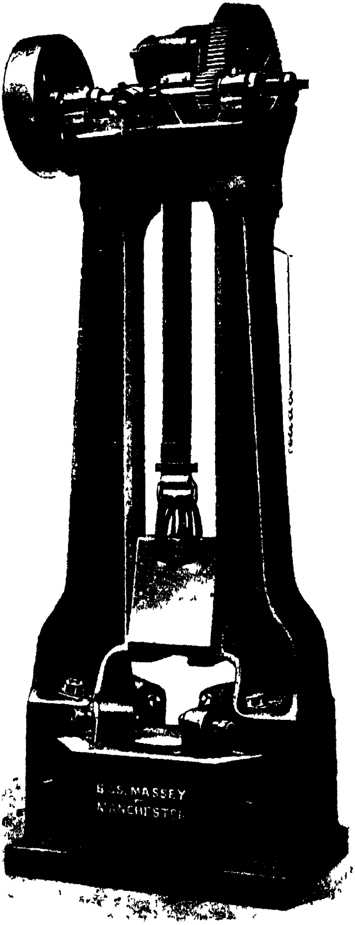


Fig. 5. Friction Lifter with Band Type Clutch
(*B. & S. Massey, Ltd.*)

pulled it is held taut, but not pulled further down nor released, the shackle in revolving tends to uncoil the cord and to release the tension. On the other hand, the shackle cannot drop because its motion back coils the cord and renews the tension. Automatically, therefore, the arrangement holds the tup suspended with the friction of the clutch just balancing the weight of the tup. The heavier the stamp the more grooves there are in the drum, with their respective friction blocks on the shackle.

Messrs. B. & S. Massey, Ltd., of Manchester, make a friction lifter on somewhat similar lines (see Fig. 5), but the clutch used is of the friction band type. The cord coiled on a winch or small drum to operate the friction clutch is used as on the system previously described, and the friction band is tightened on to a drum. As considerable heat is developed in the clutch when in constant operation, a water-cooling system is arranged to keep the drum cool.

To meet the requirements of mass production, Messrs. B. & S. Massey, Ltd. make a self-contained automatic friction drop stamp. These stamps have rigid attachments of the standards to the anvil block, give high production because of their high lifting speed and free fall, and only necessitate one operator. The operation of this hammer is by means of a foot treadle or by hand, and the stamper is able to give either a light or a heavy blow as required. This hammer is designed on lines which demand the minimum amount of attention, and its chief features are as follows.

Lifting Mechanism. Fig. 6 shows the arrangement of the friction lifter. It consists essentially of a constantly rotating drum *a*, round which is arranged a steel band *b* with friction lining. This band is anchored at one end *c* to a stud in the lifter arm *d*, and the other end *e* is carried by a camshaft running through the lifter arm and actuated by the lever *f*. To this lever is attached the pulling cord *g* which passes round the capstan bush *h* attached to the lifter shaft and so down to the operator When the cord is pulled it tightens on to the rotating capstan bush (which increases the effect of the pull) and, through the camshaft, causes the friction band to grip the drum. Thereupon the lifter arm is rotated, thus lifting the tup by means of the lifting belt *k*, the guide pulley *l* keeping the upward pull vertical as the lifter arm rotates.

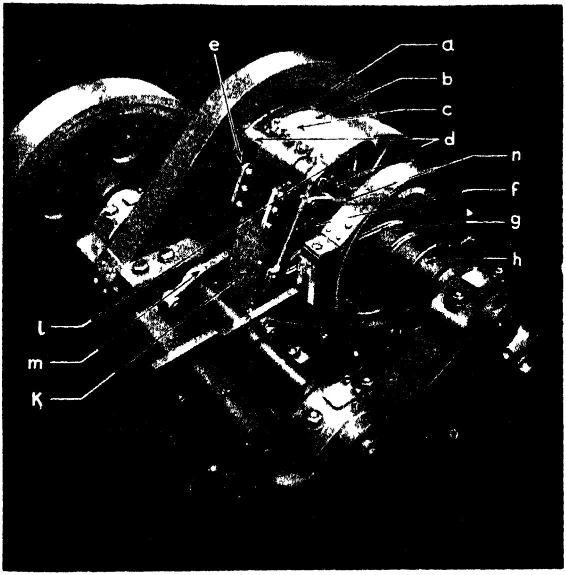


FIG. 6. ARRANGEMENT OF FRICTION LIFTER
(*B & S Massey, Ltd*)

A buffer *m* provides a stop for the arm in its extreme positions at either end of the stroke.

The spring *n* ensures a free fall by disengaging the friction band from the drum immediately the pulling cord is released.

Because the pulling cord round the capstan bush unwinds as the arm rotates to lift, it is necessary to maintain a constant pull on the cord to keep the band tight and so prolong the rise of the tup. If the cord is pulled to a certain point and then held stationary the friction of the band is at once reduced until it is just sufficient to hold the tup suspended.

Gear. Fig. 7 shows the arrangement of the gear. The trip-rod *F* is flexibly attached to the lifter arm and reproduces the movements of the tup on a small scale, its maximum travel being only a few inches. The spring *P* presses down a rod which is attached to the pulling cord. The lower end of this rod passes between four guide rollers, and is then connected to a toggle mechanism which, when the centre joint is against the stop *X*, prevents the spring from tightening the pulling cord. When the trip-rod *F* falls, the collar *Z* strikes the lip *U* of the upper toggle lever, forcing the centre joint away from the stop *X* into the position shown, and thus allowing the spring *P* to come into action. As this takes place the rod *D* is pressed down, thus pulling the cord and causing the tup to rise; whereupon the trip-rod *F* is also lifted and the cam *Y*, the back of which is supported by two thrust rollers, engages with the roller on the toggle mechanism, indicated by dotted lines, and restores it to the original, inoperative position.

When starting up the stamp and when working by hand, the toggle mechanism may be locked in the inoperative position by means of the hand-lever *H* and the stop *V*, thus preventing any automatic action. When working the stamp automatically, the hand-lever is kept above the stop.

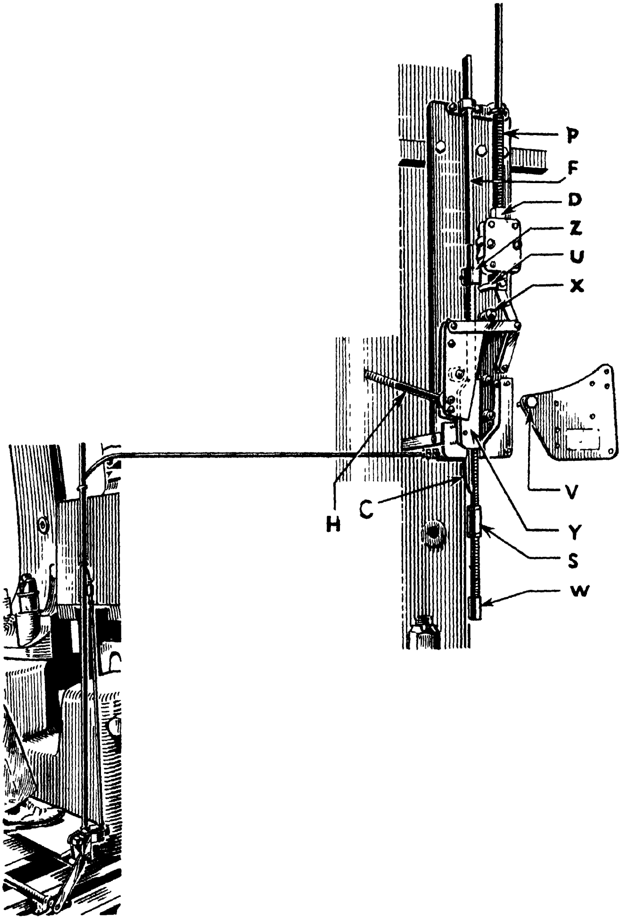


Fig. 7. Arrangement of "Simplex" Gear
(*B. & S. Massey, Ltd.*)

The height from which the tup falls is determined by the position of the sleeve *S*, which is arranged on an interrupted thread on the trip-rod so that a quarter turn of the sleeve enables it to slide up and down into any desired position. A spring catch within the sleeve locks it after it has been given a quarter turn back on the threads. The cam *Y* is loose on the trip-rod so that it is lifted by the sleeve *S* wherever this is fixed, and falls by its own weight, a stop being provided to prevent it falling below its guide plate.

Adjustment for the bottom of the stroke, i.e. for the "pick up," is effected by means of the knob *W*, which screws the collar *Z* up or down the upper half of the trip-rod, thus regulating the point at which the collar strikes the lip *U*,

The "Simplex" automatic gear makes a friction drop stamp essentially a one-man machine. It is controlled by foot-lever and is designed to actuate the pulling cord of the stamp much as the driver does in a hand-operated stamp.

When the automatic gear is put into action by means of the hand-lever *H*, the tup rises to the top of the stroke for which it is set, and is held up there without consuming any power. On depressing the foot-lever the tup falls and continues to rise and fall as long as the foot-lever is held down. The length of stroke can readily be adjusted to suit the work in hand, and the point of "pick up" to suit the thickness of the dies in use, both adjustments being made from floor level by simple single-handed movements of sleeves on the trip-rod, as described above.

A rocking movement of the foot-lever, additional to the vertical movement, allows either a light or a heavy blow to be struck as desired.

"Single" blows are obtained by releasing the foot-lever immediately the blow has been struck.

The method of fixing the lower die is in a false die-holder held in position by four large diameter screws passing through heavy forged steel poppets, secured to the block by steel cotters.

The Drive. Stamps may be driven by belt from line shafting, or by a belt from a separate electric motor, placed on the floor or in some other convenient position. The more usual arrangement, however, is the direct drive through tex ropes from a motor mounted on the headgear of the stamp. The range of Simplex Massey Automatic stamps is from 3-cwt. to 40-cwt., or, to be fuller, 3, 5, 7, 10, 15, 20, 30, 40-cwt.

BOARD HAMMER

In the board drop stamp, a timber board takes the place of the rope or belt of the friction pulley stamp, or the piston and rod of the steam stamp. To raise the tup, the bottom end of the board is fixed in the tup, usually by means of serrated wedges, and in the top part of the stamp there are friction rollers on each side of the boards. These rollers touch the board and are driven in opposite directions by gearing from the driving pulleys so that they raise the board, and with it the tup, when they are pressed against it. The rollers are mounted in bearings working on an eccentric or a tumble joint connected to a heavy bar, which puts on the pressure when the treadle is released. A release lever is arranged at the top of the stroke. When this lever is struck by the rising tup, it releases the pressure on the friction rollers, so that these allow the tup to fall. This release mechanism is adjustable, so that any length of stroke can be arranged for.

When the rollers are opened by the action of the release lever they are kept open by a latch until just as the tup strikes its blow. At the moment before it does this, however, the tup passes a catch on the side of the

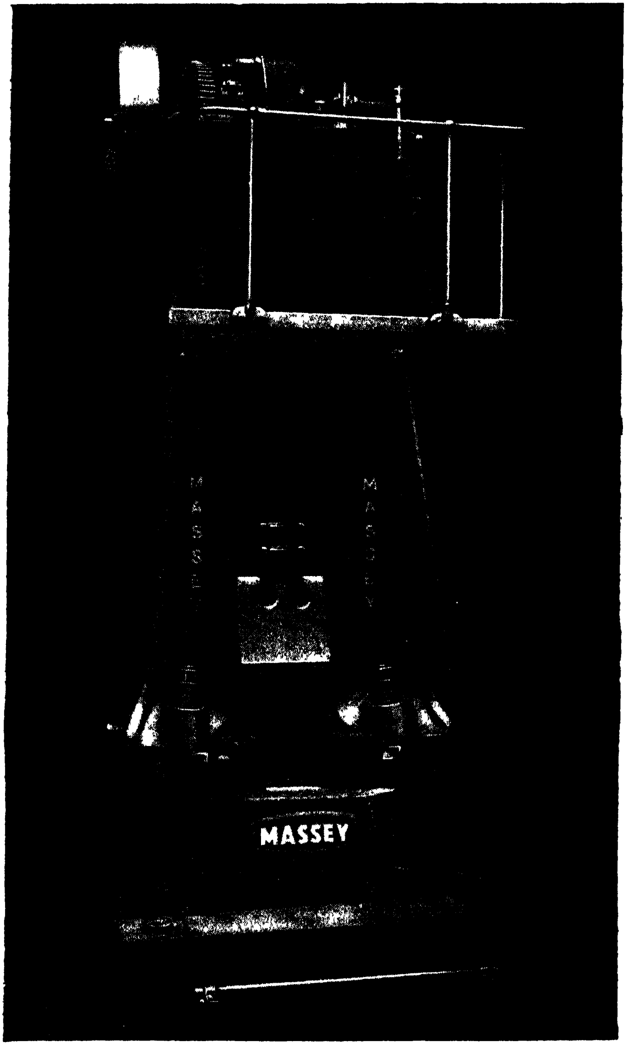


FIG. 8

(*B. & S. Massey, Ltd.*)

guide, which releases the latch, and the pressure automatically goes on to the rollers again, so that the tup is again raised and the stamp continues taking the same stroke as long as the operator keeps the pedal depressed. When the treadle is up, a clamp grips the board and holds it in the top position.

As but very few British stamp shops have ever worked the board hammer, we shall deal only with the most modern type. The motor drive board hammer, a construction that has been sought for ever since the advantages of individual motor drive for machine tools became apparent, has now been perfected in all sizes in which board drop hammers are built, from the smallest of, say, 1000 lb., up to and including 5000 lb. falling weight. With it has come the perfection of the hammer itself to the accuracy and standards of a fine machine tool. These modern hammers are as far from the board drop standards of ten years ago as the latter were in advance of the water-powered cam lift helve hammer of the Middle Ages. Engineers are so familiar with the general advantages of motor-driven machinery that a detailed review is not warranted. There are, however, some advantages accruing particularly to board drop hammers and to drop forge shops.

The maintenance of belts was formerly an important item of the board drop shop operating costs. This is eliminated entirely. The first cost of installation is reduced in many ways, obviously by the elimination of belts, line shafting, hangers, motor and motor supports, and owing to the fact that the building structure need not be designed for the heavy shaft and belt pull load. Modern standardized steel buildings of light construction can now be used. The elimination of the brace rods and of the belts results in almost doubling the area that can be served by an overhead travelling crane in the average shop. Hammers need no longer be set in definite relation to the line shaft, nor need they be set unnecessarily far from the wall, merely to provide a satisfactory length of belt drive.

The friction losses of shafting and belting are eliminated. Power consumption is less and the power factor is improved because when any one hammer of a group is not working a touch of a button takes this motor off the line, and all motors that are running are fully loaded and operate at the point of peak efficiency.

Production is increased, partly because of the greater proportion of operating time, since troubles are eliminated, partly because of the quicker pick-up of the hammer due to flywheel action and elimination of belt slippage.

In the case of the belt-driven hammers, since the surface speed of the rolls and the maximum diameter of the pulleys are limited by practical considerations, the roll diameter cannot be increased without increasing the strain on the belts, so as to more than offset the advantages gained. With geared heads the roll diameters are larger, and the pressure is distributed over a larger board compact.

Rolls are shrunk on the shaft and therefore seldom come loose. After the roll is mounted on the shaft, the outside diameter of the roll and the ball-bearing seat on the shaft are machined at one setting, turning on the shaft centres, so that they are concentric, and the rolls will not run out. The board pressure is carried on two large bearings, and there are two additional bearings on each roll shaft, one for maintaining alignment, and the other for carrying the gear tooth load. End thrust as well as radial load is carried on the ball bearings, and therefore wear and friction loss from end thrust are practically eliminated.

The eccentric is designed so that the pressure exerted on the board is constant, regardless of the angle of the eccentric, and when the pressure is removed, the maximum clearance between the rolls is provided to prevent dragging of the board. They are so securely and rigidly fastened in pairs that it is impossible for one to work ahead of the other, thus putting a strain on the roll shaft, and causing the roll to pinch one side of the board harder than the other.

The board clamps are carried in a floating head which is free to adjust itself to the boards so that the clamps cannot drag. The faces of the clamps are machined to a contour, providing the maximum clearance when the clamps are open, and allowing the ram to drop slowly and stop at any point.

FOUR ROLL BOARD HAMMER

Four roll board hammers were designed to meet a demand for the heavy type of board stamp, and the Erie Company have now put on the market hammers up to 7500 lb. falling weight.

For many years it was considered that the limit of economical pressure between the board and the roll had been reached in a 3000 lb. hammer. Since then, due to intensive experiment, it has been possible to increase the roll diameters, and thereby to build up to 5000 lb. hammers of this type, still with economical board life. The production of the Erie four roll hammer, with its perfect equalization of roll pressures, makes the pressure per inch of width of contact for a given hammer just half as much. The pressure per inch of width of contact of the 7500 lb. four roll hammer is actually less than that of the 3000 lb. two roll hammer. The boards are about a third wider, and there are twice the number of rolls, while the weight of the ram is only two and a half times as great. Four roll hammers are faster in operation than the two roll machines, and

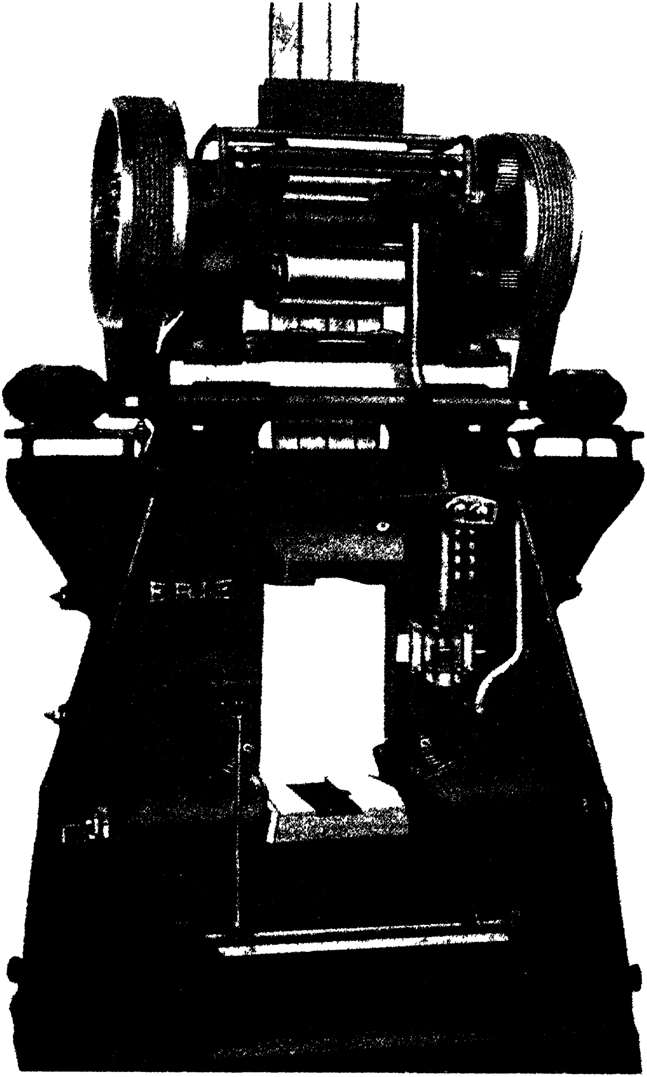


FIG 9 7500 LB ERIE ROLL HAMMER

can be used on jobs such as those requiring upsetting, where the penetration of the metal at each stroke is unusually high, so that there is practically no rebound after the blow is struck. Jobs of this type are not too practical on two roll hammers of large size, so that the four roll hammer has great advantages over the two roll type for work of a heavy nature.

The Erie Foundry Co. have now a variable stroke control. The hammer is started and stopped in the usual manner. The treadle is pushed down against a stop and the operator can put as much weight on it as he wishes. However, instead of a treadle board, he actually puts his foot on a pedal, which is pivoted on the treadle. A slight, almost effortless movement of the pedal, made by shifting the weight on this foot from heel to toe, or vice versa, determines the length of the ram stroke. He may shift his weight from foot to foot as he wishes or move his body while shifting the forging from one impression to another, without having any effect on the hammer control. Moreover, the stroke control responds in exactly the same manner, regardless of whether the treadle is up or down, or whether an adjustment is made that changes the location of the treadle when in its down position.

Experienced drop forgers will immediately recognize the advantages of this type of control on forgings such as require drawing out. Only light blows are required for fullering, heavier blows being a decided disadvantage. Not only can the operator choose light blows for the fullering, and heavy maximum blows for finishing the forging, but there is a 75 per cent increase in speed on the light blows, so that the bar is drawn out and is ready for the finishing impressions before it has lost its heat. Moreover, a great deal less power is required on the short strokes, as will be appreciated.

Anvils of board hammers are of cast steel, and weigh either sixteen or twenty times the rated size of the hammer.

STEAM HAMMERS

Quite a number of the British forge shops to-day are installing the steam-operated or air-operated hammers. They have a wide range of sizes, from, say, 1000 lb. up to and including 35000 lb., but, of course, the larger types, as will be appreciated, are built to suit some specialized work. The better-known types of steam hammer plant are built by B. & S. Massey, Ltd., Manchester, and the Erie Foundry and the Chambersburg Engineering Co., of America. In the Massey guided ram type, double-acting, steam or air stamp the range is from 10 cwt. to 5 tons.

Massey "Guided Ram" Type. A double-acting steam or compressed air stamp has a blow energy equal to that of a drop stamp of the same nominal size, but a stroke of less than half the length. It will therefore strike more blows per minute and has an output potentially very much greater. Whether this output is actually achieved depends on the heating facilities, shop organization and other factors quite distinct from the stamp itself.

In addition to high output, modern conditions demand very accurate die alignment. In these stamps this is secured by the four quite separate slides, each with multiple "Vees" and screw adjustment, in conjunction with the large diameter ram and extra deep piston.

The stamps are controlled by foot-lever up to and including the 40-cwt. size, the valve gear being of the automatic, self-acting type. In larger sizes Massey's expansion valve gear is fitted and the control is normally by hand-lever, although a foot-lever can be substituted if preferred. In all sizes the valve chest

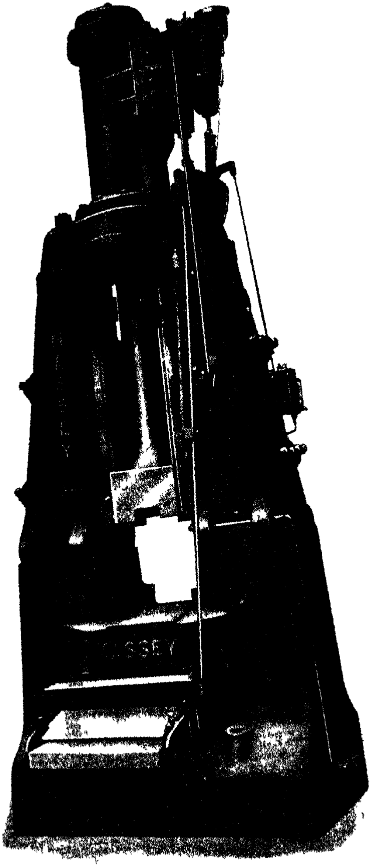


FIG. 10 10-CWT "GUIDED RAM" TYPE DOUBLE-ACTING STEAM OR AIR STAMP

(*B & S Massey, Ltd*)

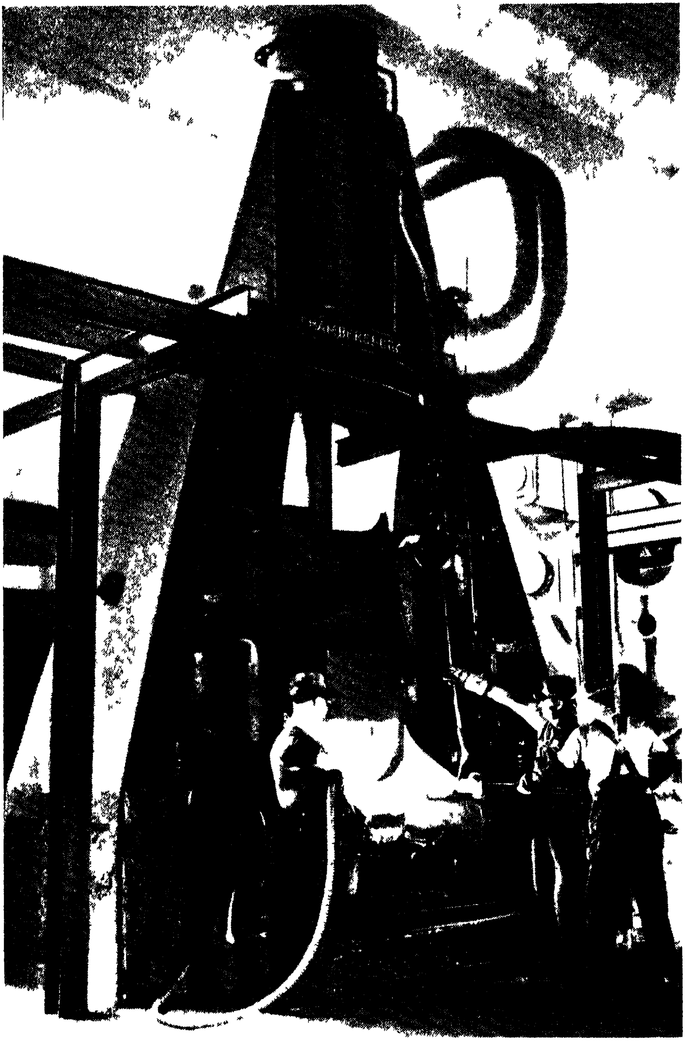


Fig 11 Chambersburg 16,000 lb. Steam Drop Hammer

(Chambersburg Engineering Co)

is a separate casting for convenience in manufacture and upkeep, and is provided with separate valve tubes shrunk into position and ground after insertion.

FOUNDATIONS

The question of foundations for stamp blocks was at one time treated differently in America as compared with this country. Now that we have in the British shops so many of the American designed hammers and presses, it has been found necessary to line the two up. A concrete base, consisting of broken brick, crushed washed gravel, or granite, is used, and in the majority of cases the anvil block is set on to timber.

It will be found advisable for the timber baulks to be strapped in some manner. The minimum thickness of board which has been proved practical is 6 in., but layers giving up to 6 ft. thickness are used on the heavy plant.

Some few years ago, many anvil blocks, particularly those which had rigidly fixed guides, were set on to the concrete facing, but the shock and vibration of the blow was transmitted to the whole of the stamp. To ease this, the stamp is now generally placed on the wooden board.

In all stamps it is necessary that the anvil block should be heavy enough to absorb most of the shock of the blow without transmitting it to the other parts of the stamp if self-contained, or to the surroundings if separately carried, and the concrete block on which it is erected must be large and heavy enough to prevent settling of the foundations under the blows. In early stamps, ten times the falling mass was usual for the weight of the anvil block, but now at least sixteen to twenty-five times the weight of the falling mass is the standard.

Whatever type of stamp is used it is most necessary that the tup should be able to fall freely in its guides, without the fall, and consequently the strength of the blow, being unduly checked by friction. At the same time, the guides must keep the tup correctly in its place, so that the two impressions of the top and bottom die come exactly opposite each other, otherwise an imperfect stamping will be formed. When there is only one impression in the die, and that in the centre, there is not much side shock on the guides. When multiple dies are used, so that work has to be done at the side of the die, considerable stress is put on the guides at the point where the blow is struck and the guides wear rapidly. The guides are usually "V" shaped, and are adjustable inwards to take up wear, whilst on the modern heavy stamps separate guide strips are fitted, which are both adjustable and renewable.

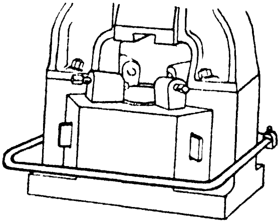


FIG. 12. FLAT MACHINED ANVIL

The anvil face is one of the vulnerable points of the stamp. In the English stamp this is usually a flat machined surface (see Fig. 12), on which the machined base of the bottom die rests, the die being held in place by the pins in four poppets fixed in the anvil. This is a very convenient method, as the die can be adjusted by the poppet pins into position to match the top die. The continual blows of the stamp on differently shaped dies, especially when the dies are of small area, gradually break up the face of the anvil and render the setting a difficult matter. To re-machine the anvil face is an awkward matter, and some English friction stamps, and certainly all modern steam and board hammer stamps, have an anvil with a steel shoe dovetailed in, the shoe itself being dovetailed to take the bottom die. When worn, it can be easily removed. This method necessitates the dies being matched according to their dovetails, and care has to be taken that the wedges do not work loose.

THE HEADING OR FORGING MACHINE

These machines are made in sizes from 1 in. to 7½ in., that is to say, work can be produced from stock of ¼ in. diameter to 7½ in. diameter. This is a tremendously wide range, and apart from speed of production and ease in operation, the quality of the finished forging has attained a remarkably high standard.

Once again, to obtain the best results they naturally must be handled properly, with sufficient forging or heating capacity, and great care must be taken that not only are the dies and tools designed properly, but that the correct steel is used. The best dies and tool steel should always be used.

In order to show the development of modern drop forging and general forging practice, rather than to illustrate machinery, we shall outline what the forging machines will do.

That the quality of machine forgings has been improved to a marked degree is a fact not generally appreciated in all quarters. In fairness to the machine forging industry—that the makers of upset machine forgings be accorded due recognition of the quality of their product—let us examine some of the features which have advanced the art of machine forging to its present position. Naturally, such improvements in the quality of machine forgings bring the method into keener competition with drop forging. Consequently, it is necessary to make a comparison of the relative merits of machine forging and drop forging operations.

In any discussion of the quality of machine forgings,

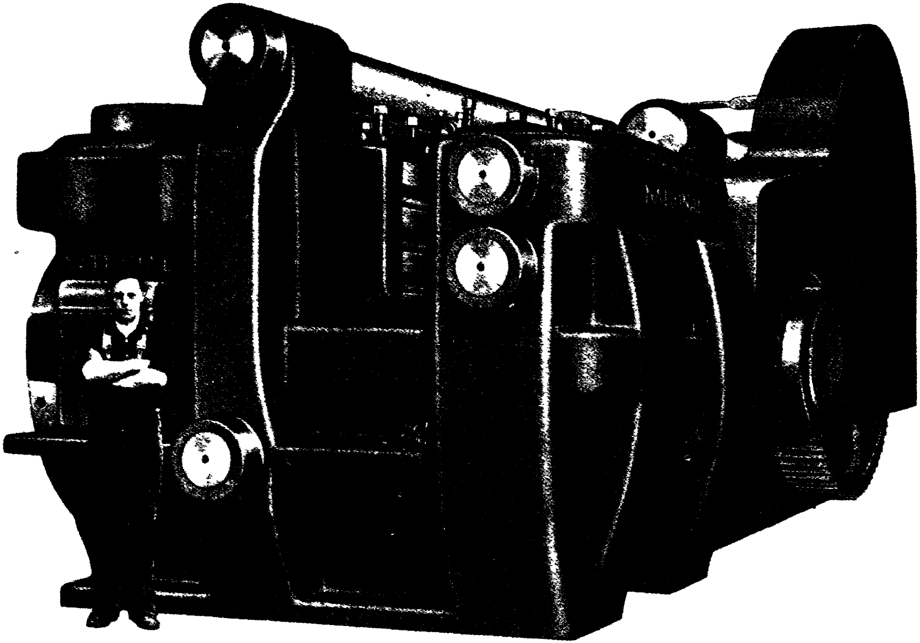


FIG. 13. NATIONAL $7\frac{1}{2}$-IN. HIGH DUTY FORGING MACHINE

the fact must be admitted that the drop hammer is the better salesman, because plenty of noise is made in accomplishing its purpose, and this naturally leaves a conviction that a material improvement is wrought in the quality of the forgings being hammered. The reputation of the upsetter or forging machine, on the other hand, is considerably handicapped by its ancestors, for in the past defective upset forgings were produced—either through defects in design and construction of the forging machine or lack of knowledge of proper die design on the part of the user, or both. A better understanding of die design and methods and a marked improvement in the quality of forging machines have materially changed the picture however.

Until a few years ago the upsetter was known as a "stoving-up" machine. The early machines did not have sufficient grip to prevent the average job from slipping, and as a result the back stop was largely depended upon to hold the material in place. The excessive spring in the bed frame, lack of proper backing for the gripping die, and poor alignment of the heading tools resulted in swollen shanks, excessive fins, and distorted upsets, which, of course, considerably prejudiced the reputation of the forging machine as a means of producing forgings of quality.

The drop hammer has for years been a highly developed tool, and improvements in it have been limited. The forging machine, on the other hand, was a crude tool which has been greatly developed and perfected, so that to-day it is possible to produce machine forgings so well that the question arises whether the forging machine or the drop hammer is the more efficient tool for the job. This comment applies to all makes of machines, not to any special make.

At first glance, the forging machine and the drop hammer do not seem to compete. Machine upsetting is a gathering-up operation whereas drop hammering is essentially a flattening or spreading out operation. Many jobs immediately class themselves without argument as drop hammer jobs or forging machine jobs.

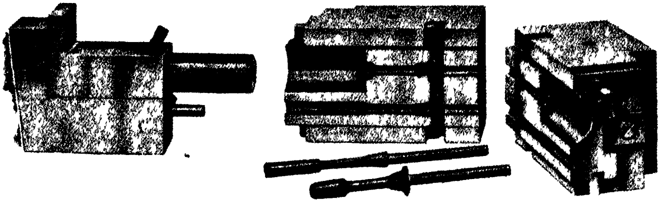


FIG 14 INSULATOR PINS

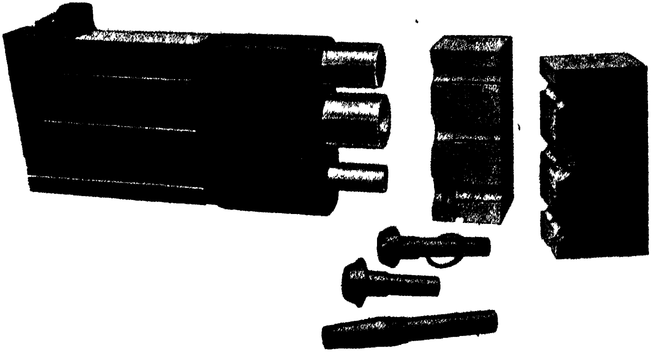


FIG. 15. AUTOMOBILE REAR AXLE DRIVE PINIONS

There is, however, a large amount of work in the twilight zone between the two methods, and it is for such work that the progress in machine forging should receive due consideration.

Figs. 14, 15, and 16 show the type of work one expects to produce from the forging machine.

THE QUALITY OF UPSET FORGINGS

There are still a few users of forgings, and now and then an engineer, who believe that the upsetting of steel, as performed in the forging machine, is detrimental to the quality of the forging from the viewpoint of strength. Quite likely, this feeling developed in the early days when forging machine die design was little understood, and when defective upset forgings were sometimes found, resulting from an effort to gather too much stock in one blow—which caused folds or buckles in the forgings. This defect, however, is so easily determined, and now so generally understood, that failure from this cause is rarely found to-day. In fact, such a failure is inexcusable, as it is now common practice to split and etch upset forgings; and should there be any defect in the grain flow resulting from bad die design, it is immediately apparent.

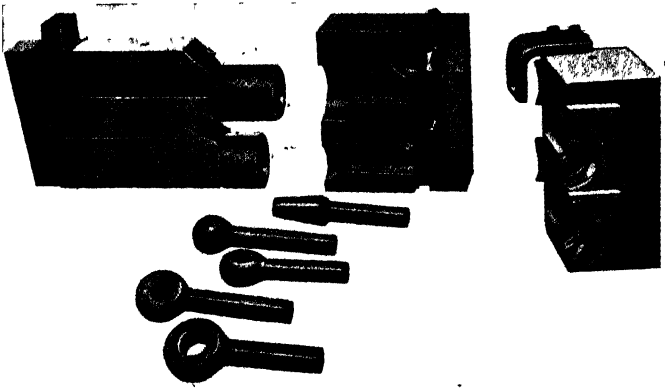


FIG. 16. "EYES" ON SHACKLES

All available evidence indicates that upsetting, properly performed, materially increases the strength of a forging. The best of the ball-bearing races are made from upset forgings, rather than from tubing or solid bars, on account of the increased quality obtained. The increase in the quality of an upset forging is particularly noticeable when a large amount of "working" has been given by upsetting from small size stock. In fact, many engineers to-day demand a maximum of upsetting or building-up by the use of the smallest possible size of stock for any given forging. The added working increases the grain refinement and strengthens the forging.

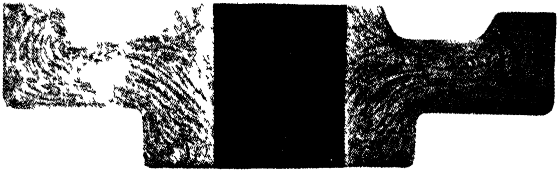


FIG. 17 ETCHING OF GEAR BLANK

The advantage gained on account of the radial grain flow in upset machine forgings is now so generally recognized that upsetting is the approved method of manufacture of a great variety of forgings, including such items as gear blanks, where maximum strength is desired. Such gears, being upset from stock of relatively small diameter, have the advantage of an added grain refinement gained during the rolling of such small stock, and this refinement is fully retained in the final forging. Fig. 17 shows an etching of an automobile gear blank, 4 in. O.D. and upset from 1½ in. diameter round stock. One would expect that such an excellent grain flow, running radially throughout the entire circumference of the blank, would ensure teeth of maximum strength—and experience shows that this is the case.

It is only on some forgings of the solid centre type, such as indicated in Fig. 18, in which the flow lines in the centre seem to be opened up, that any misgivings exist in regard to quality. Such misgivings are unfounded, as it is not a condition existing in the unetched upset, but is merely the result of the action of the etching reagent—largely in attacking inclusions which have been widened by upsetting.

FIG. 18

The choice of steel suitable for forging machine dies should have more than passing thought.

When one attempts to visualize the heating effect on the dies or tools resulting from the relative volume of hot stock, and considers the output being sought, which, of course, determines the available time in which the dies may dissipate the heat by radiation, it will be found possible to judge the necessary heat-resisting properties of the steel that must be used for the dies or heading tools. The cross-section of dies or inserts and the slender design or length of heading tools or punches indicate the required need for toughness. In addition, the strength at elevated temperatures of the material being forged and the temperature at which the forging finishes indicate the requisite hardness of the tools or dies. It is not uncommon for one set of dies, having three or four impressions, to contain as many as four different kinds of steel, or, possibly, a similar steel with a different treatment. The dies illustrated in Fig. 19 show such a condition. Where one is without previous experience, it is best to progress from a straight carbon to a chrome steel, and from the chrome steels to the tungsten steels, successively, in order that the best relation of die cost per forging may be developed. One frequently hears the statement that tungsten steels are best for all dies, but, of course, such statements must be qualified by the commercial aspect of the die cost per forging. There are times when cast iron is good enough for dies, or even for punches, if only a few forgings are to be made, and if the forging can be made at somewhat higher than

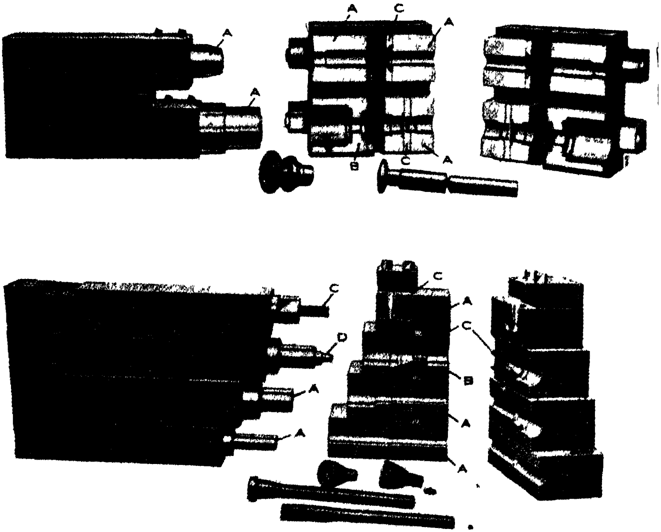


Fig. 19

A Straight carbon steel
B Chrome steel
C High tungsten steel
D. Low tungsten steel

average temperatures. On production work, of course, the better qualities of steel are almost invariably the cheaper in the end, as only with such steels are the advantages of red hardness secured.

THE FORGING PRESS

These presses are now built in England, on the Continent, and in America, and while the design of one is rather different from that of another, the fundamental principles and certainly their sphere and type of production are more or less the same. Here again, because of their rapid production, the question of heating facilities must be very thoroughly gone into. The latest type of machine is the air clutch operated, and the following is a description of the new "Ajax" solid frame forging press, both from the point of view of its construction and its capabilities (see Fig. 20).

These presses are well established in many modern production shops. They are making certain classes of forgings, both hot and cold, from steel, aluminium, magnesium, copper, brass, and other alloys with a degree of accuracy and economy far surpassing other types of forging equipment. They are employed also for the hot and cold coining of stampings and forgings made on other machines, and accomplish this work so accurately as to eliminate milling, facing, and other machining operations, on a high production basis at great saving.

Moreover, the advent of these presses of advanced design has greatly widened the field of practical press forging, and removed restrictions which handicapped progress on the older, slower, less rigid and less accurate crank, toggle, and hydraulic presses.

The patented, direct-acting air clutch, with smooth, cushioned starting at speeds far exceeding past limits, responds instantly when tripped by the operator, resulting in high outputs. It makes possible the completion, without loss of forging temperatures, of the

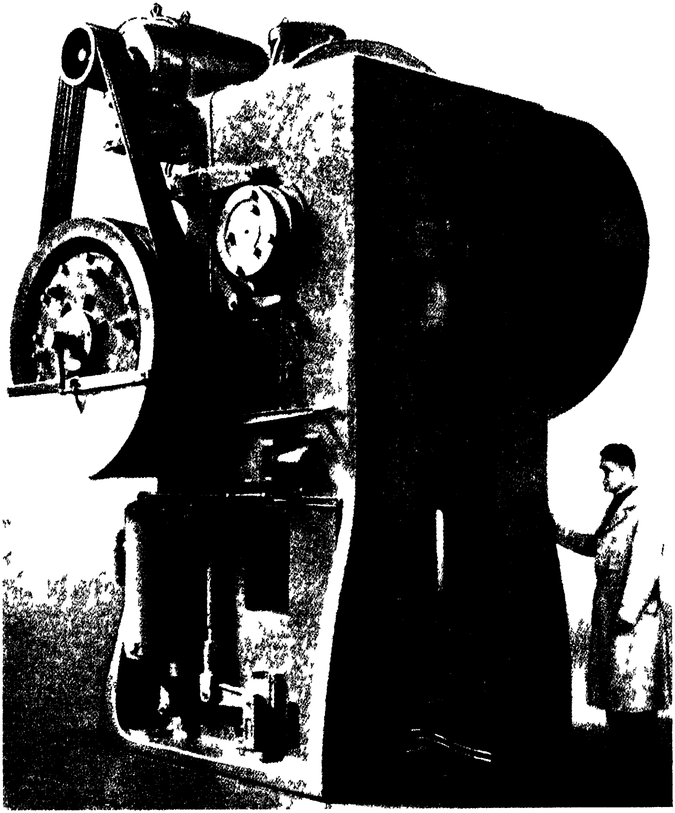


FIG 20. AJAX FORGING PRESS

several operations which may be required for some forging, such as "pancaking" or fullering, roughing and finishing.

The rear-extension guided slide gives accurate die match, which is directly reflected in the close tolerances of the forgings. It is of the utmost importance where dies are employed with multiple impressions located from side to side of the wide die space and for maintaining uniform thickness overall on long forgings extending from front to back of the die seat and ram face.

Powerful mechanical ejectors which can be timed for ejecting at the earliest point in the cycle, thereby adding substantially to die life, increase the scope to include deep-impression work and reduce drafts to the minimum. The die part line need not be located so as to give about equally easy withdrawal from either the top or bottom impressions, as with hammer dies, but can be located for forming the piece to greatest advantage considering fibre arrangement, if desired, totally confining the stock in the impressions.

Symmetrical forgings, such as gear blanks, driving flanges and rock drills, are produced from blanks of round or round-cornered square stock sheared to length and up-ended between the dies. A preliminary "barrelling" operation breaks off the scale, "pancaking" or roughing displaces and locates the stock, so that in the final forming impressions there is minimum flow and abrasion to the dies. The resultant finish compares favourably with hammer forgings, and the dimensions are even closer, not being subject to the influence of chilled flash as when repeated finishing blows are struck.

Flash can sometimes be entirely avoided by entering the top die into the bottom impression totally confining the stock, similarly to upsetter dies, and, because of the powerful mechanical ejectors in both top and bottom die impressions, draft can be almost totally eliminated. These ejectors, which are multiple in the bottom die, and the manner in which the press operates, make it possible to handle many types of forgings without sprue or tong hold, thereby saving material.

Extrusion or impact extrusion is performed on these presses both on steel and non-ferrous metals. Internal combustion engine valves, air pump valves, piston inserts and the like, where the volumetric relation of head and shank makes upset forging difficult, can be produced with great facility. If the shank is comparatively short, it may be extruded simultaneously with forming the head; if long, it may first be extruded and the head formed in a second operation, special ejectors sometimes being required for this class of work.

Extrusion may also be employed for making cup or shell type forgings such as airplane pistons where the extrusion takes place around the periphery of the punch in achieving the desired form. This method employing slugs or billets as against stamping from flat stock has much greater latitude in the permissible variations in wall thickness, reinforcements, height of bosses or lugs, etc., that can be satisfactorily formed.

When working stock flatwise or transversely, these solid frame forging presses come into direct competition with hammer forging in a limited field.

These presses are individually driven through multiple V-belts by motor of small horse-power compared to the tonnage developed, which is rather more convenient than an independent steam plant, compressed air plant or hydraulic pressure system.

Inasmuch as the pressures are self-sustained within the press frame, heavy, expensive foundations are unnecessary, and there is no noise or impact accompanying operation detrimental to buildings, furnaces, or nearby precision machinery.

The Air Clutch. The air clutch now introduced on heading machines as well as these forging presses is, without question, the greatest single improvement in this field for some years. It is a direct, pneumatically operated, multiple disc friction clutch and its smooth, cushioned starting at the high operating speeds conducive to long die life, and instant response to the effortless tripping of the foot-pedal, make possible the completion of multi-operation forging at one heat, and yield substantially increased outputs.

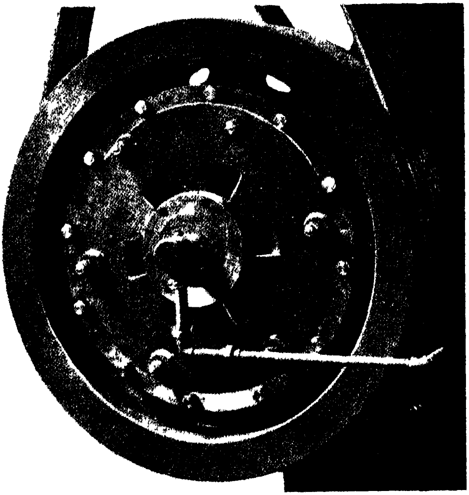


FIG. 21. AIR CLUTCH WITH SHIELD REMOVED

Rear-extension Guided Ram with Tongued-in Cover-plates. The ram is a furnace-annealed open hearth steel casting which keeps the slide rigidly in line despite the off-centre pressures developed in multi-stage dies with operations located at considerable distance from the centre line (see Fig. 22).

These presses are built in sizes 500 tons to 2000 tons, and Fig. 23 shows the type of accurate work produced.

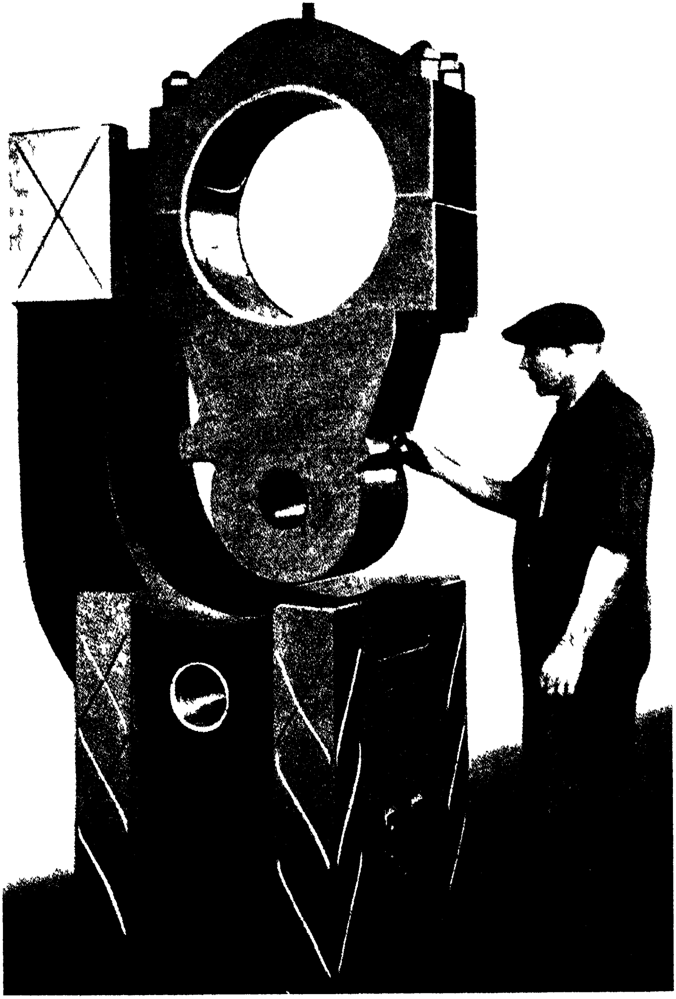


FIG. 22. RAM OF AJAX PRESS

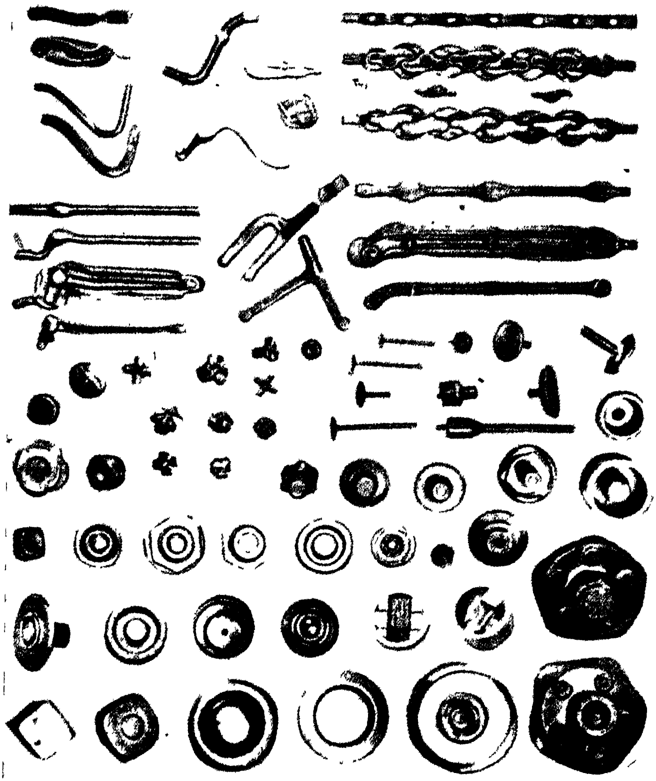


FIG. 23. WORK PRODUCED

SHOP METHODS

Owing to the fact that British shops are installing modern plant, and that they are also getting "long runs," it has become necessary to adopt many American methods.

Multiple impression dies are now used on steam and board hammers, and even the friction hammer is often worked in this manner, particularly when the stamper does not clip his own work. Team work is employed, and in many shops there are up to three stampers on one hammer, coming under the hammer in relay. Where one stamper works on the hammer he is usually fed by helpers, so that he is able to conserve his energy for the actual stamping.

Stamp shop methods have, with the introduction of modern plant, altered rapidly, and apart from the fact that the shops are now able to produce many more forgings per hour, the quality from these new hammers is of a very high standard.

Production from forge shops to-day is governed not by the amount of forgings one stamper, or one stamper and driver, can produce, but by how many the hammer can produce in a given time, the ideal being, of course, that each blow the hammer can make is used for production. In America, this fight to eliminate waste time has been going on for some considerable time, and now we in England are getting an amazing production from each piece of plant compared with only five years ago. For instance, the older type of board hammer, and friction hammer, worked by picked stampers, would produce, say, 400 10 h.p. car connecting rods of standard design in 8 hrs. To-day, on a 20 cwt. steam hammer, worked by a team of three stampers, 2000 can be made in the same time.

Methods to be used are, of course, the business of the people in charge of each individual shop, who alone are in a position to decide. As already stated, modern plant is rapidly taking its place in our forge shops, and, therefore, new methods and ideas are being used to run it.

Rhythm is the aim of the shop superintendent, and to achieve this he must have the whole co-operation of each department. He tries to arrange his stamps, fires and presses in the best order. One very good way is to have his stamps and presses arranged so that not only are they each a complete unit, but the stamps, fires and presses adjoining can share in the work, should more than one unit be necessary for any particular job.

Co-operation means that the correct tooling must be supplied by the die shop, and in sufficient quantity to enable a long run to be continued without changing, it being remembered that modern plant and methods wear out the tools quicker than, at least in most cases, these can be produced.

It is also necessary to see that the steel is the correct handable length, and of a size which will make the job with the minimum amount of flash, that it is supplied by the steel stores to its hammer before production commences, and that care is taken to ensure continuity of supply.

Heating plays a most important part in the forge shops, and to attain maximum production about 25 per cent excess heat must always be at hand.

Idle time must be cut down to a minimum, and to do this, the man or men working on the stamp, forging press or upsetting machine must be able to concentrate on the actual production, and not have to worry about heating, drawing off the heat, clipping or returning the stock to the furnace. Adequate assistance to eliminate idle time must be arranged, whether the order be for 500 or 50,000.

DIES FOR DROP FORGING

The subject of dies for drop forging is so connected up with methods of working that the two subjects must, to some extent, be treated together. The quality of the steel to be used for the dies depends to a considerable extent on the work to be done. The steel-makers of Britain and America have gone carefully into the manufacture of special steels for stamp dies, heading machine dies, and forging press dies, and can now offer steels to meet all cases. It is essential to use just the right type of steel, so much so that the different plant calls for different steels to produce the right forging.

The following are the chief characteristics of a good forging—

(1) It is free from physical defects, of the lightest weight consistent with adequate strength and an ample factor of safety. It must function with certainty under the maximum load it is designed to carry.

(2) It is a duplicate of the one which preceded it from the dies, within a very close margin of tolerance.

(3) It must be produced with a minimum of flash, with the top and bottom halves matched in near perfect alignment.

(4) It must have the grain flow of the material so disposed that the physical characteristics are the maximum obtainable with the metal used.

To produce forgings in accordance with these specifications calls for drop hammer equipment with certain characteristics which may be tabulated as follows—

(1) A drop hammer of adequate power and capacity.

(2) A tool which will retain through the maximum years of usage its ability to keep the dies properly matched.

(3) A tool which will accomplish a given amount of work with a minimum number of blows in a minimum of time, at the same time making efficient use of the power applied.

(4) A tool which is invariably under the operator's

control, this control being exercised with the least possible physical and mental effort on the part of the operator.

(5) The wearability and reliability should be as near 100 per cent as is attainable, thereby giving maximum continuity of service.

(6) Last, but by no means least, the tool should be safe for the operator to work on throughout its useful economic life.

For large stamps of fairly plain shape a high carbon steel is generally used in its normalized condition, but for dies of intricate shape, and for such dies as place great strain on the steel owing to the way the metal of the stamping has to be forced into them, alloy steels are used, which are heat-treated and oil-toughened. generally after the dies have been cut.

The requirements in a carbon steel for stamping dies are that it be as tough and hard as possible, and yet reasonably easy to machine.

Alloy steels, which require hardening, must have a high degree of toughness after cooling, great strength, together with toughness in the hardened face, the capacity to harden to a reasonable depth, and machinability.

The Drop Forgers' Association, both of Britain and America, after a series of tests, have published specifications of steel for die blocks which they have found to give satisfactory results, as follows—

For Carbon Steels—

Carbon . .	between	0·55 and 0·65	per cent
Silicon . .	not more than	0·30	,,
Manganese .	between	0·50 and 0·80	,,
Sulphur .	not more than	0·05	,,
Phosphorus .	,, ,,	0·05	,,
Nickel . .	,, ,,	1·00	,,

to be supplied in normalized condition. Brinell hardness to suit requirements.

For Nickel Chromium Steels—

Carbon	0·50–0·60 per cent
Silicon	0·30 max. ,,
Manganese	0·50–0·80 ,,
Sulphur	0·04 max. ,,
Phosphorus	0·04 max. ,,
Nickel	1·25–1·75 ,,
Chromium	0·50–0·80 ,,

to be supplied annealed only, or hardened and tempered to suit requirements.

For Nickel Chromium Molybdenum steels—

Carbon	0·50–0·60 per cent
Silicon	0·30 max. ,,
Manganese	0·50–0·80 ,,
Sulphur	0·04 max. ,,
Phosphorus	0·04 max. ,,
Nickel	1·25–1·75 ,,
Chromium	0·50–0·80 ,,
Molybdenum	0·25–0·30 ,,

The steel for die blocks should be sufficiently forged to toughen it. Square and oblong blocks should be forged from ingots having twice the area of the section of the block, and the way the fibre of the steel runs should be marked. Circular blocks from 8 in. to 12 in. diameter should be forged from ingots of 40 to 50 per cent greater area and larger sizes from ingots of 20 to 30 per cent larger area. They should be forged down to an area at least 70 per cent smaller than the block, and then up-ended and widened out to the proper diameter. This is to bring the fibre of the steel partly across the section (see Fig. 24).

In cutting the dies, the way the fibre runs has to be considered. The effect of driving the metal of the stamping into the die puts considerable stress on the sides of the die, tending to split it open, and, whenever possible, the grain or fibre of the steel should be in the line of the greatest stress. In a die which is long and narrow or oval shaped, the metal can move most easily along the line of the greatest length, so that the greatest stress is across the narrow part (see Fig. 25).

In preparing the dies, the faces are machined and the outline marked out. The cutting of the dies is a highly-skilled operation. In the early days the die-sinker drilled, chipped, and scraped out the metal, but there are now many machines available for die-making, the principal one used being the profiling machine. There are also semi-automatic die-sinking machines, which work from a pattern or dummy and reproduce the design in the die. The finishing of the dies has, however, nearly always to be done by hand, and scrapers, files, and rifflers are used.

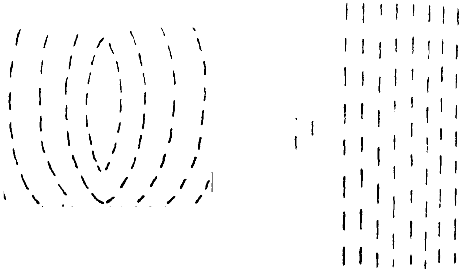


FIG. 24. RESULT OF UP-ENDING ON GRAIN OF STEEL

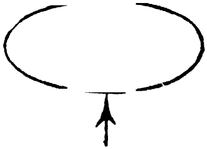


FIG. 25. ARROWS SHOW THE LINE OF GREATEST STRESS IN DIE

If the bottom die is held in a dovetail it is necessary that the two halves of the dies shall be matched from one side, so that they will coincide exactly when placed in the stamp. Where the dies have only one impression it is important to keep the impression central, so that there shall be little or no side strain brought on to the guides owing to the tup kicking-over. In multiple dies, where there are dummying impressions or roughing-out dies as well as the finishing die, it is usual to put the finishing die as centrally as possible, as the heaviest blows are struck on this.

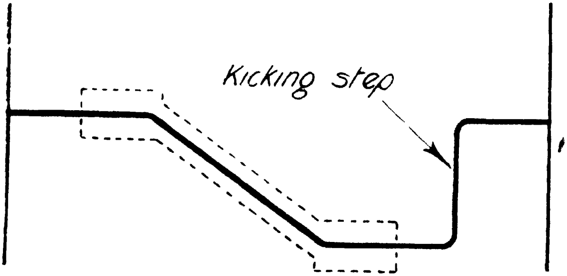


FIG. 26. METHOD OF PREVENTING KICK-OVER

In some dies it is not possible to have the face of the dies flat and horizontal, but part of the division of the dies must be at an angle. This, naturally, would make the top die kick-over badly, and to prevent this what is called a kicking step is used (see Fig. 26). It is sometimes possible to avoid having a kicking step, and to balance the dies by making a double stamping, and this is much to be preferred (see Fig. 27).

When irregular stampings, that is, stampings which are not symmetrical about a centre line, are used, it is often a matter for consideration which part shall go into the upper die and which into the lower die. It is a generally recognized rule to put the high parts, such as pegs or bosses, into the top die, for it is found that the metal flows more easily into the top die. This may appear strange at first, until one considers that the tup delivers the positive part of the blow and the anvil only the negative part, the forces at work in the lower die being in the nature of a reaction, while the actual energy is in the tup and top die. The parts of the stamping which require consolidating and spreading out should be placed in the bottom die.

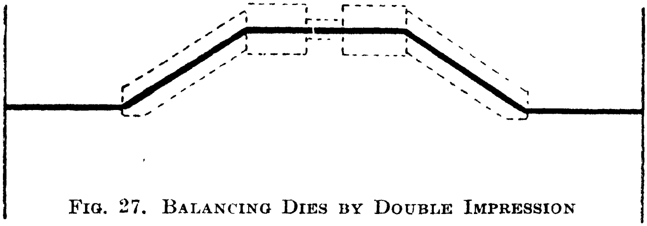


FIG. 27. BALANCING DIES BY DOUBLE IMPRESSION

In Britain the dummying of the stock is generally done on a separate stamp, when using friction plant, in what are called open dies or tools, and a much lighter stamp can be used than is necessary for the much more severe work of forcing the metal into the closed dies for finishing. The dummying generally consists of fullering, drawing out, or bending operations, although splitting and punching are sometimes done. In multiple impression dies, generally used on board and steam plant, where all the operations are done on the one stamp, the dummying operations are done at the sides of the die, and the finishing impressions for the actual stamping are placed in the centre of the dies. As the stamp has to be powerful enough to give the finishing blows, it follows that it is much more powerful than is necessary to do the dummying, and frequently the stamping proper is done in stages, a roughing stamping and a finishing stamping, in which case a lighter stamp can be used. Fig. 28 is a sketch of multiple dies for stamping a double-ended spanner. *A* is a fuller for drawing down the stock between the parts to form the jaws, while *B* rolls the stock further to bring the right amounts of metal into place to form the jaws; *C* is the rough stamping impression, and *D* the finishing one, and on one corner is the cutter-off, which finally separates the stamping from the bar.

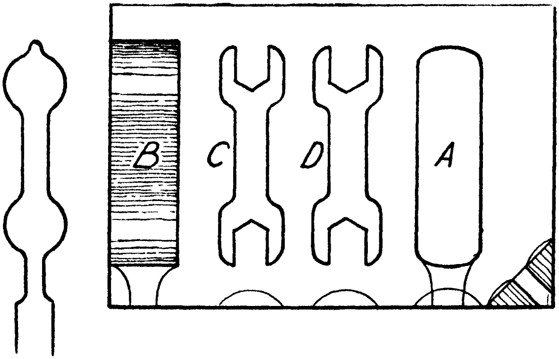


FIG. 28. MULTIPLE DIES FOR STAMPING DOUBLE-ENDED SPANNER

The dummying or preparation of the stock for placing in the final finishing dies is now an important consideration. In the early days of drop forging it was considered sufficient to place a hot bar of metal of sufficient area to cover the die impression between the dies, and to let the stamp do the rest. There was consequently great waste of material, heavier stamps and more blows were required, and the stampings were imperfect in shape compared with the modern product and varied considerably. Present-day practice is to shape the stock so that when it is placed in the finishing dies there is sufficient metal to fill the different parts of the dies, and not too much in any place to cause excessive fin or flash.

With such great strides having taken place in the stamp shops and remembering that mass production from these shops wears out dies and tools in a much shorter time than it takes to produce them, the die shop must, of course, be brought up to date.

The lay-out of the die shop is of as much importance as that of the stamp shop, and only the very best of equipment should be used. Machines have once again dispensed with a tremendous amount of the hand labour, and to-day we are able to fit our shops out with independently-driven units for each type of machine required, such as—

The Keller automatic die-sinking machine, of one or more spindles, together with the Keller universal cutter and radius grinder, which, by the way, can cope with the cutter grinding for all the vertical milling machines, such as the Gortons, with or without duplicating tables, from which very fine and accurate work can be produced.

Cincinnati vertical millers, Nos. 3 and 4.

Herbert V46 and V47, and so on.

Shapers, both light and heavy duty, with swivelling and tilting device such as Churchill, Redman and Butler.

Gap lathes in most useful sizes by Churchill, Redman, Lang, and Swift, and the usual up-to-date planers and 36 in.–42 in. open-sided crank planers.

All these are most essential for modern continuity, and the management would do well to make the die shop their first consideration.

USES OF THE FIN

It is, of course, desirable in making the stampings to use the least possible amount of material, as any extra over the weight of the actual stamping is cut away as waste, and from this point of view it may seem that it would be ideal if the stamping could be made without fin or flash. This, however, is not the case, the flash having a very important duty to perform, and being very necessary in making most stampings. There are exceptions, which are mentioned later.

Let us consider what takes place in the dies when the stamping is being made. The first blow of the stamp falls on the hot metal and partially forces it to fill up the dies, and the following blows complete the process. If there is not enough metal to fill the dies the result will be an imperfect forging, and in the final blow the faces of the dies will have to take the full impact of the blow. If there is just enough metal to make the forging, it will be very difficult to get the stock dummied to such a shape that all the metal can be forced into the dies. In all probability part of it would be caught as a fin between the faces of the dies, so that the stamping itself would be short of metal and imperfect, and the more so as the dies would not meet face to face because of the fin. Supposing, however, all the metal could be forced into the dies, they would meet face to face at the final blow, and have to take the shock of this blow. The result would be that the die faces would be speedily shattered by the tremendous stress of the stamp blow being taken by two cold and practically unyielding surfaces. Cracks would soon develop, and the dies be ruined.

The function of the fin or flash is to act as a cushion between the die faces, and as it spreads on all sides it helps to keep the force of the blow evenly spread over the dies. Apart from this, the fact that the fin is formed enables the metal of the stamping to be thoroughly consolidated in the dies, because they never meet face to face, and in the final blows, when the dies are full of metal, the metal is made solid and homogeneous, in the action of forcing out the excess metal into the fin.

As the two die faces do not actually meet, it naturally follows that the thickness of the stamping will be more than the total depth of the two dies by the thickness of the fin, and allowance for this is made when making the dies.

TOO LARGE A FIN DETRIMENTAL

It is important that there should not be too much waste in the flash, however, as apart from the waste of metal a large amount of flash has serious disadvantages. The bigger the flash the more difficult it is to get the stamping down to size, as the flash cools more rapidly than the body of the stamping. To prevent the flash coming into contact with the flat faces of the die, which tends to develop cracks extending into the body of the stamping, a method is adopted known as flash and guttering.

SIZE OF STOCK

This question of flash raises the consideration of the proper size of stock to be employed. Generally speaking, it may be said that the bar can only be reduced in stamping, so that the cross-section of the billet or bar employed should not be less than the cross-section of the largest part of the stamping, for there must be metal enough to fill the dies and form scrap. When the stock is dummied before the final stamping, its shape should be such that metal can flow from the thicker parts to the thinner, as it will not easily flow from a thinner part to the thicker parts. The metal in the dummied stock should be so placed that the flash is fairly evenly distributed, as excess of scrap in one part may cause distortion or undue strain to be set up in the stamping, because the large part of the flash cools before the rest of the stamping.

LONG THIN-BODIED STAMPINGS

Stampings are often required which have a long comparatively thin body with one much wider part in it. To apply the rule mentioned before, that the bar from which the stamping is made must be equal in cross-section to that of the largest part of the stamping, would mean that, to avoid a great deal of waste, it would be necessary to do a large amount of work on the smaller part of the bar to reduce it before the final stamping operation. To overcome this a smaller bar equal to the requirements of the smaller part of the stamping is used, and this is upset to form the larger section. For this purpose the upsetting machines are employed in which the bar is gripped, while the hot end is compressed in the direction of the length of the bar, and the metal forced outwards into dies of the requisite shape. This forms a head or a collar, as the case may be, on the bar in the part where the larger section is required.

BENDING THE STOCK

When bending is required in the preparation of the stock, and board or steam plant is used, it is done under the stamp, or usually on the dummy when friction plant is used.

When the bending is of a more complicated nature, as in the case of a large crank forging, a power bending machine is often used. The shaping of the bar in making crank forgings, by bending it to the approximate shape of the crank, is not only for the sake of saving metal, but to ensure that the grain of the metal shall be guided round the webs of the crank and follow in one continuous stream from one end to the other.

To enlarge on the question of crank making, and also to show the advantage of using modern plant, the following table may prove of interest—

HAMMER	DRAFT ON DIES	NO. OF BLOWS TO ROUGH AND FINISH	STOCK	COUNTERWEIGHT ON CRANKSHAFT	REDUCTION IN STOCK TO BE MACHINED OFF	PRODUCTION CRANKS PER HOUR
1939 (B) 10,000 lb.	7½–10 deg.	32 (2 hammers required).	Round—(3 ct. per lb.).	Separate forgings.	—	35 to 40.
1939 (E) 12,000 lb.	3½ deg.	18 (2 hammers required).	Square—(2 ct. per lb.).	Integral forged.	20 per cent	45 to 50.
1940 (E) 16,000 lb.	1½ deg.	8 (1 hammer required).	Square—(2 ct. per lb.).	Integral forged.	60 per cent less.	55 to 60.*
RESULTS—60 per cent heavier	One-fifth of draft formerly used.	One-fourth the number of blows.	About 10s. per crank save on stock alone.	No machining of counterweights now required.	60 per cent less stock to be machined off.	50 per cent increase in rate of production.

Die life between recuttings increased 50 per cent.

* On a special test a production of 75 eight-throw cranks in one hour was obtained.

When the stock has to be bent before stamping, it is advisable to thicken-up the metal at the point of the bend by upsetting or rolling, otherwise the metal on the outside part of the bend is thinned out, and this may result in a shortage of metal at this point, whilst the inside of the curve, unless reinforced, as indicated in Fig. 29, is liable to make a sharp angle, which in the stamping may be the starting point of a crack. Also the dies should not grip the metal at the bend.

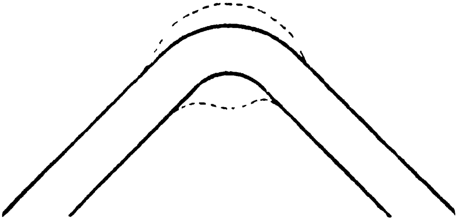


FIG. 29. SHOWING (DOTTED LINES) HOW IT IS ADVISABLE TO THICKEN-UP THE METAL AT A BEND PREVIOUS TO STAMPING

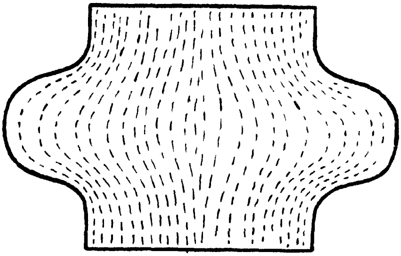


FIG. 30. EFFECT OF UPSETTING ON GRAIN OF STEEL IN GEAR STAMPING

The flow of the grain or fibre of the metal in the stamping requires important consideration. It should run, if possible, in the direction of the stress which is likely to be put on the stamping when it is afterwards used for its ultimate purpose. For instance, if a gear wheel is stamped from a flat bar the fibre will run across it in line with one of its diameters. Consequently, when the teeth are cut in it, some of them will have the grain from point to root of the tooth, others will have the grain at an angle, and some will have the grain across the tooth, and will therefore be less able to stand the pressure put on them than those teeth with the grain running along the depth of the tooth. To prevent this, such stampings are usually made by cutting pieces off the bar and up-ending them in the stamp. By this means the grain is forced outwards, forming a " U "-shaped curve and ensuring that each tooth, when made, will have the greatest possible strength.

FORKED STAMPINGS

In stampings of a forked character the stock is frequently split, and the split opened out in the preliminary operation. If this is done by shearing or cutting, care must be taken that the end of the split does not form the starting point of a crack in the stamping. A better and safer plan is to fuller, in a dummying operation, the metal into its approximate position with a thin connecting piece between. This connection can be cut away, if necessary, before the final stamping, but it can often be left in place and removed as part of the flash after stamping.

The work of the men who operate the stamps usually includes the setting of the tools or dies, the actual stamping, and sometimes the trimming of the stamping by shearing the flash in a press while the stamping is still hot. Where modern methods are employed and modern hammers and furnaces are used, the heating of the work is done by heater or heaters, and the clipper is employed at the adjacent press so that the stamper is only called upon to stamp.

When this method is employed production is very much higher and one finds to-day that an enormous amount of cold clipping is desirable.

To check any discrepancy in the contour of a cold clipped forging, which naturally cannot be re-struck on a hammer, a hydraulically operated setting press of varying tonnage is used. This cold clipping also has the advantage of being able to be done at any time after the stampings have been made.

The days are now past when it was necessary, by the use of an oily swab, to oil the dies during most of the operation, and certainly between each stamping, because the possibility of freezing or sticking in the tools, that is to say, when the tools are in good working order, is almost eliminated by the speed and sharpness with which the new plant operates.

As already pointed out, modern plant does not call for dies with excess taper allowance, so much so, in fact, that many of the jobs now being forged can, even on the taper walls, be coined in a coining press flat to within plus or minus 2½ thousandths.

FURNACES

The heating of the stock needs careful attention, otherwise the stampings and forgings, however they be made, will suffer in this operation.

The metal has to be hot enough to be easily worked, and to hold its heat long enough for each or all operations to be finished, as if the stamping is continued after the metal is too cold for proper working, surface cracks are nearly sure to be started. On the other hand, great care has to be taken that the steel is not over-heated or burned as this will spoil the physical properties of the metal, and result in bad stampings.

The temperature at which the particular metals are best worked and what temperature they will stand advisable. Rapid heating of these furnaces is maintained with absolute uniformity of temperature and precise control of heating in respect of both temperature and time. In addition this type of furnace is simpler in operation, has low running costs, inexpensive maintenance, is safe and has clean working conditions.

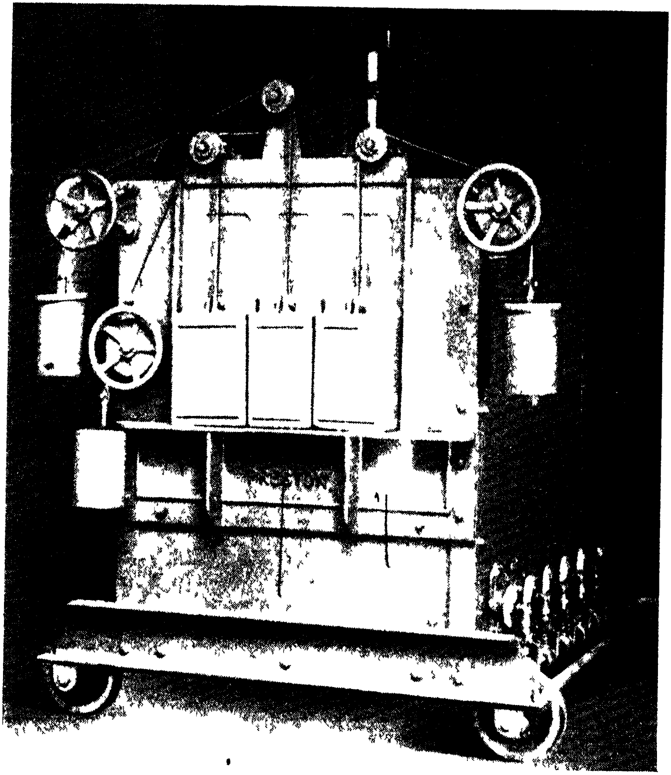


FIG 32

(*Thermic Equipment & Engineering Co.*)

The design incorporates fans to circulate the accelerated convection currents, which result in the rate of heating being increased, the limit being usually set by the rate at which materials can absorb heat. The rate of heating in circulated air is nearly equal to that obtained in the liquid baths without the many disadvantages inherent in the salt bath method. Uniformity of temperature is maintained to within 2½° C. plus or minus—with the extremely sensitive automatic temperature control.

Furnaces with circulated atmosphere are of standard type and sizes, whereas a series of small interlocking doors can be provided for small billets.

OIL-FIRED FURNACES

Perhaps the type of furnace most generally used in our forge shops to-day is that fired by oil, in which great progress has been made in the last few years.

The oil-fired furnace builders realized that the output of the stamp shop depends quite as much on the heating and handling facilities as on the stamps themselves, and to-day we have oil fires of sufficient heating accommodation to ensure that the costly plant may be worked to capacity. The advantage of the oil-fired furnace is that it can generally be readily moved from one place to another, and therefore always be used in the most convenient position. It occupies rather less floor space than a coal or coke furnace, and moreover no flue or chimney is necessary. It is simple and reliable to run, once the flame has been set, and it does not require the skilled firing called for by coal or coke furnaces.

Independent regulation of the air and oil supplies, combined with efficient atomization, enables smokeless combustion to be effected. The comparatively low blast pressure which can be used secures economy in oil and air consumption, and makes it possible to use low pressure fans.

The Burner. The burner illustrated in Fig. 33 has a filter embodied to ensure clean oil, and therefore a regular flow and steady combustion. It will work with a low blast pressure and a crude fuel oil can be used. The air supply is controlled by the damper valve *A* in conjunction with the two shutters *B*, thus allowing the maximum air velocity to be maintained right up to the jet. The oil supply is connected to the stop valve *D*, but is controlled by the lever *G*, the position of which is adjusted by the set-screw *H*. A movement of the lever across its quadrant causes oil to be flushed through the burner, thus clearing the jet, and a spring ensures that the lever returns to its original position against the set-screw. Immediately on entering the burner the oil passes through a filter. This filter may be cleaned by rotating the knob *E*, the dirt falling into a sump which can be emptied by removing the handle *F*.

The burner is secured to an angle bracket attached to the furnace. The body of the burner swivels at *C* on the damper pipe, so that the angle of the flame may be varied, or the nozzle turned right away from the furnace when not in use, thus preventing carbonization in the burner. The set-screw *J* serves as an adjustable stop for the body of the burner in its operative position.

A satisfactory pre-heating arrangement for oil and air supplies results in great economy. With oil, the advantage is mainly when starting up, as the heat of the furnace, once it is going, is usually sufficient to cause the oil to flow freely through the pipes and burner. It is, however, also an advantage to have the oil in the surface tank heated by, say, a steam coil to about 100° F.

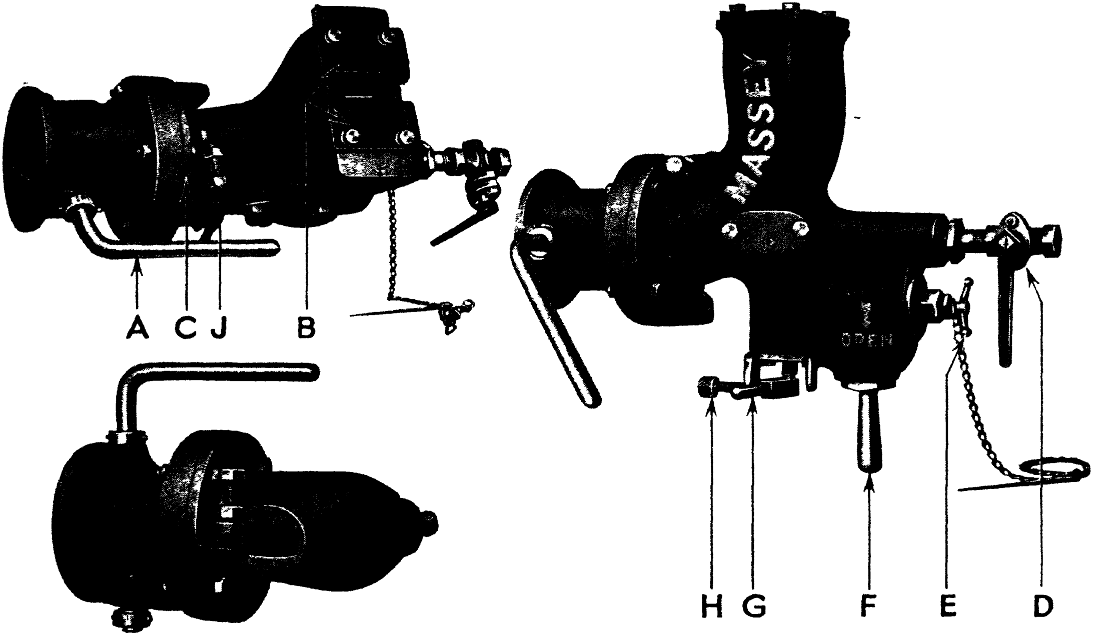


FIG. 33. BURNER
(*B. & S. Massey, Ltd.*)

Fig. 34 shows an electric oil pre-heater, suitable for fitting in the oil supply pipe immediately before the burner, and capable of use with any make of furnace. It is claimed that, at a cost of one-tenth of a penny, this oil pre-heater halves the time required for starting up the furnace.

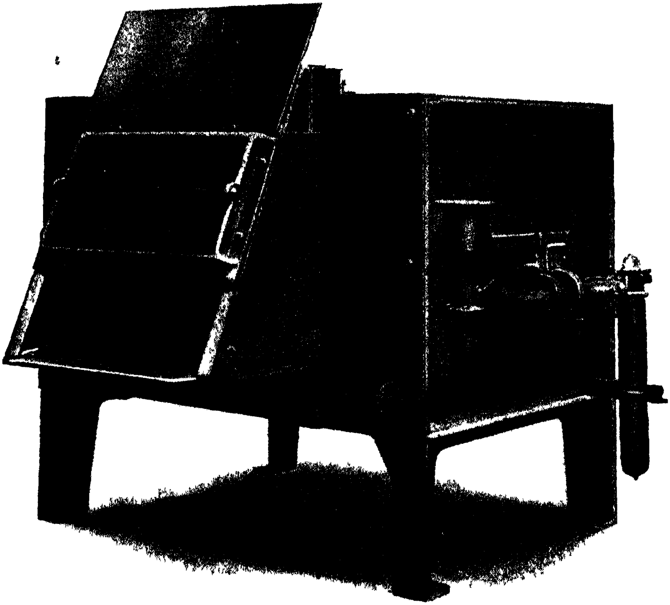


FIG. 34. ELECTRIC OIL PRE-HEATER
(*B. & S. Massey, Ltd*)

PULVERIZED COAL FURNACES

Perhaps the most modern forge fire of to-day is that fired by pulverized coal fuel, and while it is not yet generally used, amazing results and certainly most inexpensive firing are not only claimed by the manufacturers, but also proved by the yet few users.

The advantages of burning coal in pulverized form consist mainly in high efficiency of combustion, coupled with flexibility and ease of control. High efficiency of combustion is obtained by such an intimate mixture of superfine particles of coal with air that combustion takes place almost instantaneously, as in a gas. The size of the coal particles is such that 75 per cent will pass through a screen having 40,000 holes to the square inch. The amount of air can be controlled so that conditions may be oxidizing or reducing as desired. Flexibility of control arises from the design of the Atritor, which permits only a small proportion of the total air required for combustion to pass through with the coal; the additional air required, known as secondary air, is introduced at the burner.

Combustion is so complete that the resultant ash deposited contains practically no carbon. At the same time no smoke is produced and excess air can be reduced to the minimum.

The degree of flexibility which can be obtained from an Atritor installation is almost unbelievable. Any change in the coal feed to the pulverizer is communicated to the burner in less than 30 seconds, so that the heat requirements of the furnace can be met or even anticipated with ease and certainty.

The class of coal to be used must have very careful consideration, and it is not possible to use pit-head refuse, but rather advisable to use the best coal obtainable with a low ash content.

The Atritor. The Atritor Unit Coal Pulverizer is a self-contained unit. It pulverizes entirely by attrition, hence its name, and consists principally of the feeder, metal separator, pulverizer, and fan, shown in Fig. 35.

Forge furnaces for heavy forgings or heavy drop stampings are usually non-continuous, having one, two or three doors, and fitted with a waste heat boiler.

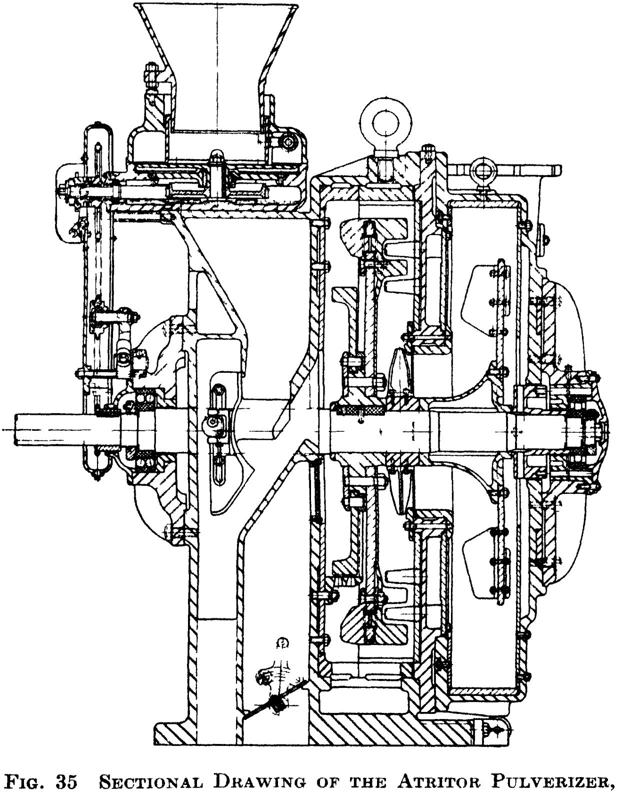


FIG. 35 SECTIONAL DRAWING OF THE ATRITOR PULVERIZER, SHOWING FEEDER, METAL SEPARATOR, PULVERIZER, AND FAN
(*Alfred Herbert, Ltd*)

It is now established that for forging, pulverized coal firing after the installation of the plant is rather cheaper than gas or oil.

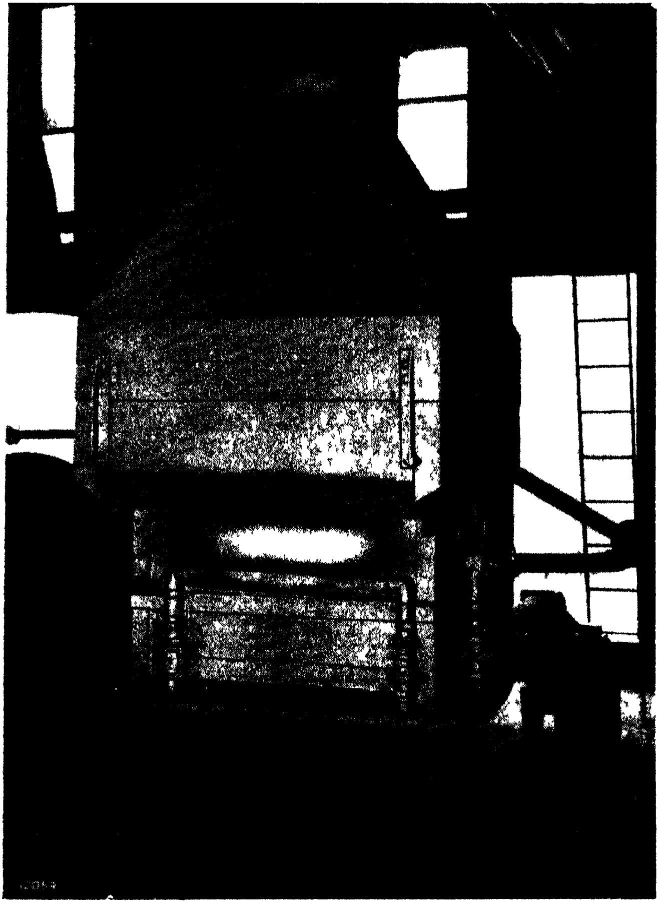


FIG. 36. SMALL FURNACE FOR LIGHT FORGINGS
(Alfred Herbert, Ltd)

REMOVING THE FIN

The trimming of the stamping or freeing it from the flash or fin is done in presses with a punching tool of the same shape as the stamping to force the stamping through a bed with a similar shaped opening. This operation is either done while the stamping is still hot, that is, as soon as the stamping is finished, or when the stamping has either been cut off on the die or press, or, in the case of a billet stamping, as one single piece, and allowed to cool, the trimming then being done in the cold stage.

Like the rest of the forge and die shop equipment, the present-day presses have reached a high standard, and can be put to such uses as clipping, bending, setting and coining. Most of the presses installed in forge shops to be used in conjunction with the hammers up to and including 150 tons are fitted with what is known as a side sprue cutter. These cutters are fitted at the side of the press and are operated by the press crankshaft and their own connecting rod. The cutter operation is brought into play to remove the flash after the stamping has been trimmed when worked off the bar.

The general arrangement of the modern forge shop is to install a trimming press or presses adjacent to each hammer, so that the products from the hammer require the minimum of transport to the trimming press. When jobs are made requiring trimming and piercing operations, the double-ended press has many advantages, because it will be seen that the forging has merely to be taken from one side of the press to the other.

Generally speaking, the press is operated by a foot-lever, or when by hand, two levers are employed, so that both the operator's hands are never in proximity to the tools.

When cold clipping is being done, it is, of course, essential that the presses be guarded, but in the case

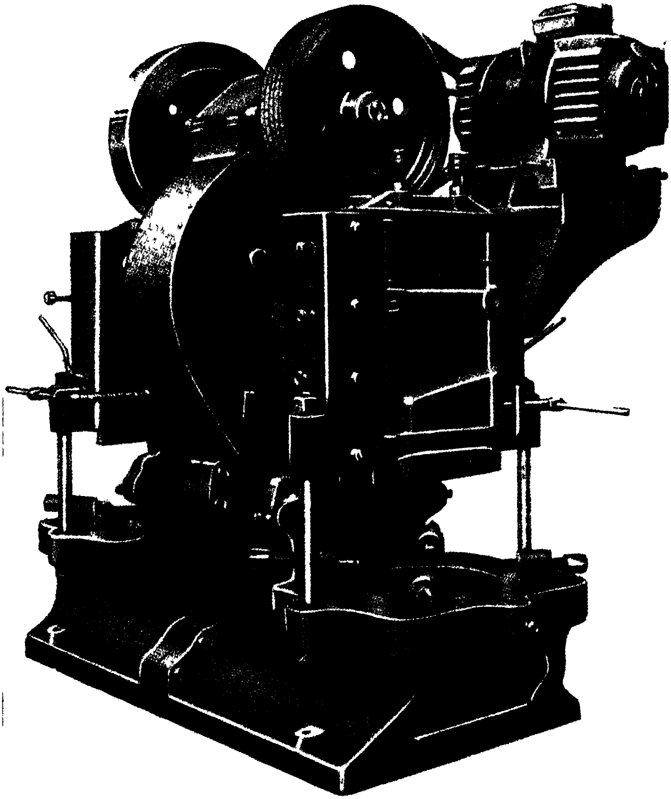


FIG. 37. DOUBLE-ENDED STRIPPING PRESS

of hot clipping being done in single form either from billet or cut-off stamping, the operator of necessity must use tongs. This ensures that there is no possibility of his hands coming into contact with the tools, although even then adequate safety measures should be employed.

Presses to-day have a stroke and capacity equal to any hammer output, so that there is no necessity, even when cold clipping, to have the forge shops inundated with unclipped work.

CLEANING, HEAT TREATMENT, AND INSPECTION

Stampings can seldom be used in their rough state, even after they have been trimmed. They are first pickled or shot blast, this being a very much cleaner process, inspected, and, if required, normalized or heat-treated. Perhaps this rather raises a point for debate, owing to the fact that shops producing a great tonnage get a better flow from the stamp shops to the dispatch when the material is put first into treatment, and then inspected. This latter method can only be introduced when the forge shops have their own inspectors, whose duty it is to see that the right type of work comes off both hammers and presses. Apart from the fact that the heat-treatment department should be modernly and adequately equipped a properly equipped laboratory is a practical necessity, not only for the analysis of steels but also for the Brinell hardness testers and tension and compression tests.

BRASS STAMPINGS

Stampings are also made in other metals as well as in iron and steel. Brass of certain compositions can be stamped hot in the same way as steel is done, but the ordinary stamps are only used for shallow work. Hot brass is better formed in dies with the blow from a press, rather than the sharp heavy blow of a drop stamp, and a special type of press has been evolved for this work.

This press is of the screw type, the screw being vertical, working in a fixed nut carried in the top of an arched frame. To the top of the screw is keyed a heavy flywheel, which lies horizontally. On each side of this flywheel there is a large friction disc, and these are driven by pulleys. The face of each of these friction discs can be pressed against the flywheel rim and made to rotate it, so that one disc raises the screw and the other lowers it.

The bottom of the screw carries a head which runs in guides, the end of the screw being free to revolve in the head. The head carries the top die, and the bottom die is held in the base of the press. In operation, a hot piece of metal is placed on the bottom die. The pressure disc, which lowers the screw, is brought into play, and the screw brings the discs together. The energy of the rotating flywheel supplies the force to press the metal into the dies, after which the opposite pressure disc is put into action and the screw raised. It is found that the hot brass shapes itself into the dies under this steady continuous pressure very readily. The stock is cut off so as to supply enough or very little more than is wanted in the finished pressing, and there is little or no fin or flash usually formed. Brasses of comparatively low copper content, such as are used for extruded bars, are usually used as a stock. Pressings can be made to the finest of limits as to size, and the metal is very homogeneous. Certain of the bronzes and coppers are also used in this process.

GENERAL EQUIPMENT

The equipment of a modern drop-stamping works which deals with a considerable variety of work comprises many things besides the stamps and their accessories. As indicated previously, upsetting machines, swaging hammers, hydraulic and other presses are called into use, not only to prepare the stock for the stamps, but to finish off the stampings when they are made.

In addition to these machines, hacksaws, cold circular sawing machines, and croppers are used to cut the bars into convenient sizes. The machines being fed by overhead floor-operated cranes must, of necessity, be adequate when using the modern board and steam plant and heading machines, the reason for this being that so much of the work is done in the single piece, namely, in billet form.

The building, particularly of the forge shops, should be most carefully gone into. While it is advisable to use most of the available floor space, hammers and presses should never be cramped. The fires should be built sufficiently near the hammers to prevent excessive walking, but in no instances should the heat of the furnaces interfere with the comfort of the operator. Stanchions should be so placed that a good workable, central gangway is obtained, and the amount of ventilation should be at least 12 changes per hour.

Whatever type of plant may be installed, or whatever size work is to be made both in the die shop and in the forge shop, an overhead travelling crane, of sufficient capacity to lift from the floor and to lower to the floor all tools and plant should be embodied in the building. Not so much the amount of labour, but certainly the amount of time saved by this mechanical lifting method, is enormous.

SECTION XXI

DIE-MAKING, PRESS WORK AND STAMPING

BY

LEONARD BRAME

SECTION XXI

DIE-MAKING, PRESS WORK AND STAMPING

It would be futile to attempt to explain in full all the various branches to which the above title has reference, but it is possible to give a brief and varied account of the fundamental principles in simple form. These will, in a way, act as an introduction, and the more intricate and complicated examples will then more easily be understood as actual practice and experience are gained.

The intending learner need not be discouraged, as a casual glance through the following pages will prove the simplicity of some examples used in modern practice. Toys, typewriter parts, domestic articles, and aircraft parts are typical of the things that are produced in quantities by means of tools which are adapted to presses of various types. In fact, it is difficult to look round the shops or the home without seeing some article that is the product of the press.

For those readers who have had no mechanical experience at all, technical training or night school is recommended, so that such subjects as Geometry, Drawing, and Mathematics may be studied. A good kit of tools and instruments will become necessary as time goes on. These will be mostly expensive and delicate, and great care will have to be taken both in handling and storing them, as described later. Apart from personal equipment, various machines are necessary for the making of press tools. These cannot be described in detail, but their uses and the methods of operating them will become apparent as experience is gained. They include lathes, milling machines, drilling machines, universal and surface grinders, shaping machines, and hardening equipment.

Although the processes of hardening and tempering are of vital importance to the tool-maker, it is very difficult to lay down any hard and fast rules which will be a guarantee of success. So much depends on the brand of steel and the use for which it is intended. There are, to mention but a few, oil, water and air hardening steels, combination and high-speed steels, all of which have their various uses and treatments. Plunging oil-hardening steel into water is disastrous, and plunging water-hardening steel into oil is useless. Therefore it is necessary to get acquainted with the quality of steel being used, study the formulae supplied by the makers, and act accordingly. Allowance for distortion and final grinding must always be made, and sight must not be lost of the fact that a tool can be too hard or too soft, either of which may result in an expensive renewal.

INTRODUCTION TO THE WORKSHOP

Assuming a lad who is quite a "raw hand" wishes to train as a tool-maker, it is advisable for him to enter a works as shop boy. This will give him a good chance to look round and become familiar with shop methods. After a year or so he should prove himself useful in the fitting shop, and from there he can go to the machine shop, finishing up, after several years of work and study, in the tool room. If a lad has had a good technical training, he may be able to start direct in the tool room, but he must still keep at his studies for several years. In both cases it is necessary to pay particular attention to all that is shown, and to be thorough in all work that is done, since tool room work is very important and calls for great care and precision, any error occurring in this department being reproduced throughout in the finished product.

For the first few years, progress will appear to be slow, perhaps boring and discouraging, but soon simple machine operations or fitting will appear commonplace, and eventually one will be entrusted with a complete tool.

PRECISION INSTRUMENTS

Micrometers are the most essential and most often used of all precision instruments. Their uses are varied according to the size and nature of the work for which they are designed. In ordinary practice, they vary from 0–1 in. to 4 in., 5 in., or 6 in., and are designed for outside, inside, thread and depth measurements. These various types are best explained by reference to illustrations in any good tool catalogue, such as that issued by Starrett, Brown & Sharpe, Moore & Wright, etc. They are made with ratchet feed for fine, accurate reading, and test pieces are supplied to check their accuracy from time to time. Great care must be taken with micrometers, as a blow or fall is liable to upset the reading considerably.

Verniers. These instruments have rather similar uses to micrometers, although they are usually brought into service on work of a larger type. They are made in various sizes for inside and outside measuring, and are useful for checking, turning and boring, parallel distances, setting calipers and dividers, etc.

Height Gauge. This instrument is closely related to the vernier, but its chief use, as its name implies, is for measuring and marking heights. It is mounted on a heavy base, and is used on the surface table for marking off and checking to fine limits.

Vernier Protractor. For measuring, marking off, and checking angles accurately, this instrument is absolutely essential. It is finely graded to measure degrees and minutes.

Calipers, inside and outside, dividers, scribing blocks, feelers, vee-blocks, etc., are all necessary units of the tool-maker's equipment, but as their uses are more or less apparent, it is not deemed necessary to dwell in detail upon them.

BLUE PRINTS

Usually the first information to reach the tool-maker, regarding a certain tool or set of tools, is in the form of a blue print or prints, either of the actual tools required, or of the component itself. In the latter case it is left to the tool-maker to design the tools to suit the particular part, and to arrange the proper sequence of operations with the minimum amount of scrap always in mind—an important point which is dealt with, in full, later.

For the sake of illustration, we will assume that the blue print issued is of the article that is to be produced, and will therefore be of the type shown in Fig. 1. All measurements, it will be noted, are given after the bracket has been bent, so the first step to take is to determine its length in flat blank form. This is best done by making the bending tool first (see Fig. 2). On completion of this, it is possible, with the aid of adjustable register plates, to ascertain the exact amount of metal that is taken up in the bend.

MAKING THE TOOL

To make the tool, first get all parts cut off and machined square on the edges, and all surfaces ground true. Mark off the "Vee" of the die 45 degrees either side of the centre line. Machine carefully in the shaping or milling machine close to the line, and finish off to

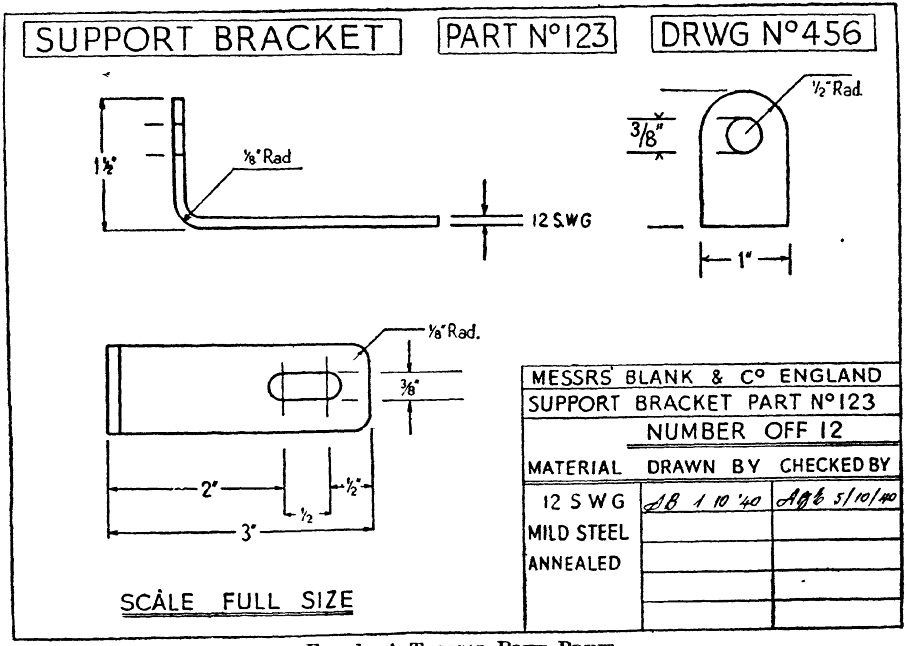


FIG. 1. A TYPICAL BLUE PRINT

a smooth surface by filing. Drill and tap all fixing holes, including those by which the adjustable register plates are to be fixed. Next, machine the punch to the same angle, namely 45 degrees, either side of the centre line, and finish with the file. Small punches, such as the one in question, pass right through the punch plate, and are burred over on the back end. This must be a tight fit, and square in assembly.

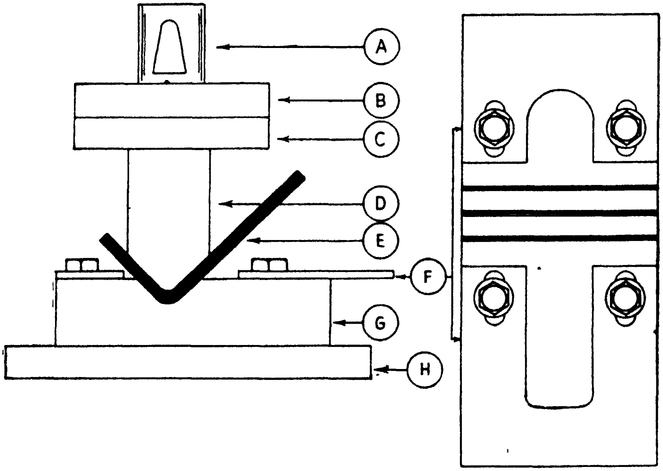


FIG. 2. VEE BENDING TOOL WITH PLAN VIEW OF ADJUSTABLE REGISTER PLATES

A is the spigot, by which the punch or upper portion of the tool is fixed to the press. This is screwed tightly into the spigot plate *B*, which is again screwed and dowelled to the punch plate *C*. The punch *D* passes tightly through the punch plate and is burred over on the top edge to prevent withdrawal. It is made of cast steel, hardened and tempered. *E* is the fitting or blank. *F* shows the two adjustable register plates. *G* is the die, also made of cast steel, hardened and tempered, and is securely screwed and dowelled to the base plate *H*. The lower portion or die is held in the press by means of clamps, holding on the projecting ends of the base plate.

The spigot is screwed to the spigot plate, which in turn is screwed by four screws (one in each corner) to the punch plate, after which it is dowelled, to prevent any movement taking place. The adjustable register plates take the form of those shown, and can either be of cast steel, hardened and tempered, or of a good-quality case hardening steel. The punch and die have now to be hardened and ground ready for the final assembly and try-out.

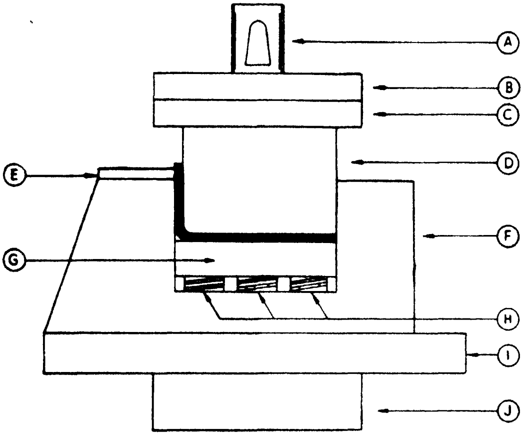


Fig. 3. Spring Pad Bending Tool

A. Spigot (mild steel)
B. Spigot plate (mild steel)
C. Punch plate (mild steel)
D. Punch (cast steel)
E. Register plate (mild steel)
F. Die (cast steel)
G. Pad (cast steel)
H. Coil springs
I. Base plate (mild steel)
J. Spring housing (mild steel)

Fig. 3 shows an alternative form of bending tool which gives far more accurate and better-class production than that shown in Fig. 2.

Fig. 4 shows an orthodox design for a blanking and piercing tool, suitable for the production of fittings similar to that being described.

Accuracy in all operations must be strictly observed, and for that reason the marking off will be described in detail, to emphasize its importance.

Fig. 5 shows the die in position, placed on parallel strips on the face of the surface plate or marking off table, which is a large cast-iron plate with its surface machined and scraped absolutely flat. Before the die is ready for this process, it must be machined perfectly square, and the surfaces ground, polished and discoloured to a deep blue by placing over a gas ring. As soon as the die is true, accurate and nicely coloured, it can be placed on the parallels for marking off. With the pointer of the height gauge the centre line is scribed, and a note made of the reading, as it is from this line that all other lines are determined by adding or subtracting as the case may be. When all the necessary lines have been scribed, the die may be turned on its end as in Fig. 6, and further lines scribed. It will now be seen why it is so necessary for the die

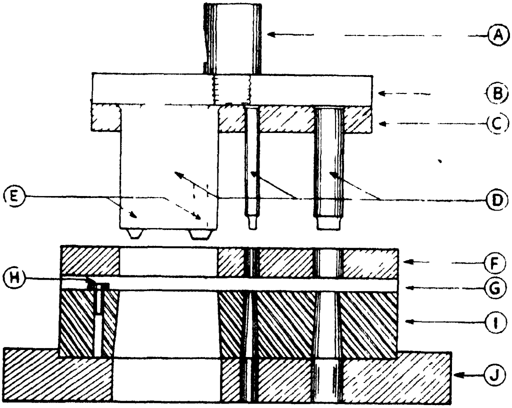


FIG. 4. SECTIONAL DRAWING OF BLANKING AND PIERCING TOOL

A.	Spigot	*F.*	Stripper plate
B.	Spigot plate	*G.*	Guide plates
C.	Punch plate	*H.*	End stop
D.	Punches	*I.*	Die
E.	Pilots	*J.*	Base plate

to be square. In some shops this is not the practice, but instead the die is clamped to an angle plate, and is positioned by using a square on the surface table. This may be quicker in the first place, but makes it difficult at a future date should it become necessary to set up for any purpose. Some slight error in the product may mean checking over, and the alignment of the die is usually the first to come under suspicion.

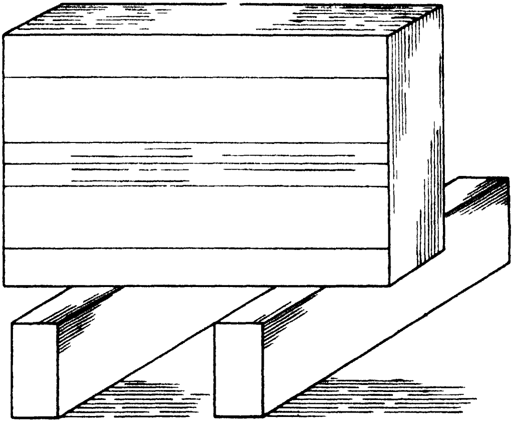


FIG. 5. SHOWING FACE OF DIE PLACED IN THE FIRST POSITION OF MARKING OFF

With the marking off finished, all necessary points where the lines intersect may be lightly centre dotted. It is rather a common fault for the beginner to be heavy with this operation, thereby making it difficult to scribe nice clean circles with the dividers. After using the dividers, these centre dots may be enlarged sufficiently for drilling purposes. Drilling, of course, must be carefully done, always using a smaller drill than the finished size, thereby allowing a hole to be "drawn" with a round file, should it be out of centre.

In any case it is advisable to leave a small margin in the piercing holes, which can be removed to size with a "D" bit or morse taper reamer. If reference is made again to Fig. 4, it will be seen that all piercing holes and the blank aperture are tapering towards the underneath edge. This allows the metal, once it is cut, to drop easily through the tool.

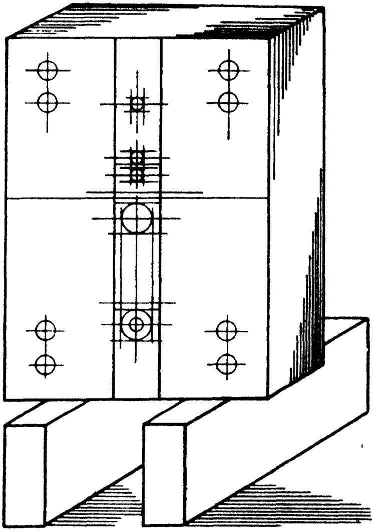


Fig. 6. Showing Die in Final Stage of Marking Off

After drilling comes the filing, which again must be carefully done, seeing that the degree of taper is uniform and corresponds with that of the taper reamer. A final check over, all necessary screw holes tapped, dowel holes reamered, piercing holes tapered, die filed to shape and size, register pinhole drilled, and the die is ready for hardening, tempering and grinding. Following this, all holes, etc., are transferred through to the stripper and punch plate. Strict alignment here is most essential, to ensure smooth working. The punches can be made, hardened and tempered and fixed to the punch plate. The stripper should be made an easy sliding fit over the assembled punches. All that remains now to be done are the spigot pilots, register pin, and stripper guides.

FINAL ASSEMBLY

Regrind the face of the die (this may have become chipped during fitting), and finish with a fine flat carborundum stone. Drive in the register pin. Assemble stripper, stripper guides and die to base plate. Place the punch plate, with punches assembled on the surface grinder and grind over the working face. Insert pilots, and rivet over on the back edge to avoid withdrawal. Screw and dowel to spigot plate, and carefully slide the complete assembly through the stripper, when it should, if alignment is correct, pass easily and smoothly into the die itself. If this should not be so, do not in any case use force, as damage will be caused either to the cutting edges of the die or punches. The only remedy is reassembly.

The tool at this stage is now ready to be assembled in the press, and actually tried out, using some soft metal, such as brass, for the trial. The product will show at a glance whether the tool is functioning correctly. If satisfactory, the proper gauge metal may be used, the result checked over for size, and finally passed-out as ready for production.

ALTERNATIVE METHODS OF LAY-OUT

Fig. 7 gives the plan views of four alternative methods of planning the lay-out for this same fitting. It should be mentioned here that much metal and operating time are saved by careful planning and,

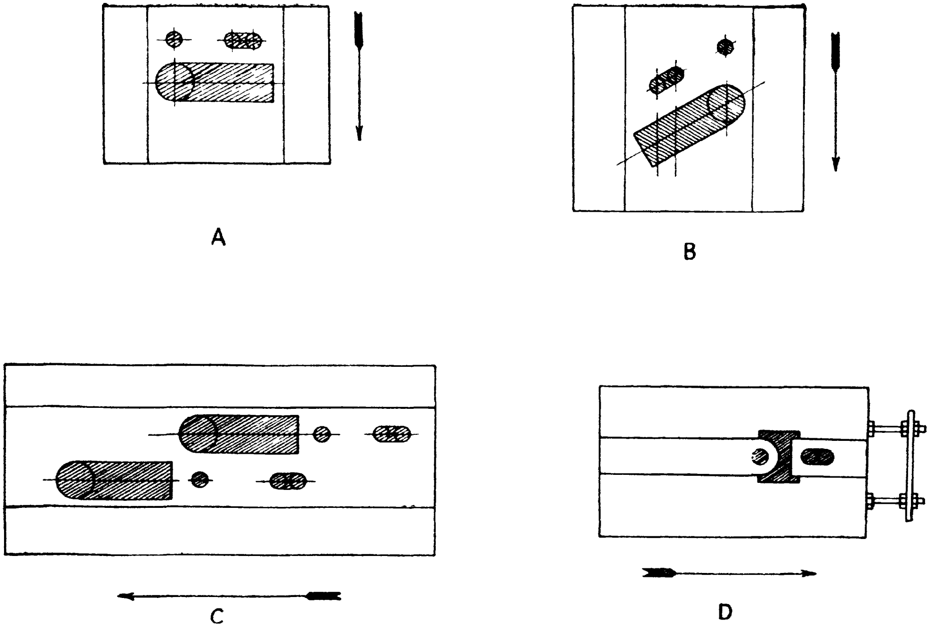


FIG. 7. FOUR ALTERNATIVE METHODS OF LAY-OUT

The arrows denote the direction in which the metal is fed.

although not applicable to this particular example. many fittings are so shaped that it is possible to arrange the lay-out in such a way that one blank interlocks the other. This is dealt with in more detail later. *A* shows the follow-on principle, the same as the one previously described, but with the grain of the metal running lengthways, as in the direction of the arrow. *B* shows the same principle again, but designed on the angle. This proves very advantageous in some instances. *C* is the same as in Fig. 4, but has a double set of punches, thereby producing at double the speed. Although slightly more expensive to make, its cost is soon covered by increased and cheaper production. *D* is a typical crop and piercing tool. Quality is sacrificed here as standard strip metal is used, either round edge or sheared. For cheap production, this type of tool gives satisfactory results, and is capable of producing large quantities without much attention.

In all cases, tools such as these which have been described reach their limit of perfect production, and have to be re-ground for further service. This precaution is strongly recommended at frequent intervals, as a blunt tool not only produces bad work, but is liable to do expensive and sometimes irreparable damage to the tool itself.

DETERMINING THE BLANK SIZES

Referring back to the blue print, it will be seen that the sizes of the fitting are only given after the bend has taken place, but we can gather that it is approximately 4½ in. long in the flat. Therefore, taking this as the first try-out, cut a blank to size in 12 B.G. (0·109) plate, and drill the holes as shown. Adjust the register plates (see Fig. 2) to suit the blank, and in such a position that the bend occurs in the right place. The whole unit is now ready to set up and try in a hand press. Check the result, and if not to drawing, alter the blank or the position of the register plates, as the case may be. When the desired results are obtained the correct position of the register plates must be secured by dowel pins, after which the die may be hardened and tempered, and finally assembled in readiness for the production of the blank and piercing tool.

SPRING PAD BENDING TOOL

The tool shown in Fig. 8 is the complete spring pad tool, with the side plates removed for the purpose of showing clearly its working principles. These side plates are as shown in Fig. 9, and are so constructed that it is possible to remove one while the tool is in the press, thereby making it possible to see what is actually occurring under working conditions. The top portion is too simple to need any explanation at all, as it resembles the one previously explained, with the exception of the form of punch. The deciding unit in the bottom portion is that marked *G*, which has to be large enough to accommodate the length of the fitting from the extreme end to the bending line, and it is from this that all other measurements are arrived at. *H* and *I* are the two cast steel jaws, which are snugly housed in the mild steel bolster *J*, the whole being fixed to the base plate *M* by screws and dowels in the usual manner. Holes are counterbored in the bolster to accommodate as many springs as possible, not only for extracting the fitting, but for ensuring a true bend; $\frac{3}{8}$ in. dowels are fitted in holes marked 1 to pass through the side plates, and the holes marked 2 are tapped to receive the screws by which the side plates are fastened. In planning to suit the individual fitting, it must be so designed that the bottom of the pad makes solid contact with the bolster at the end of the stroke, by which means it is possible to planish the fitting as well as bend it. Where possible it is advisable to register off

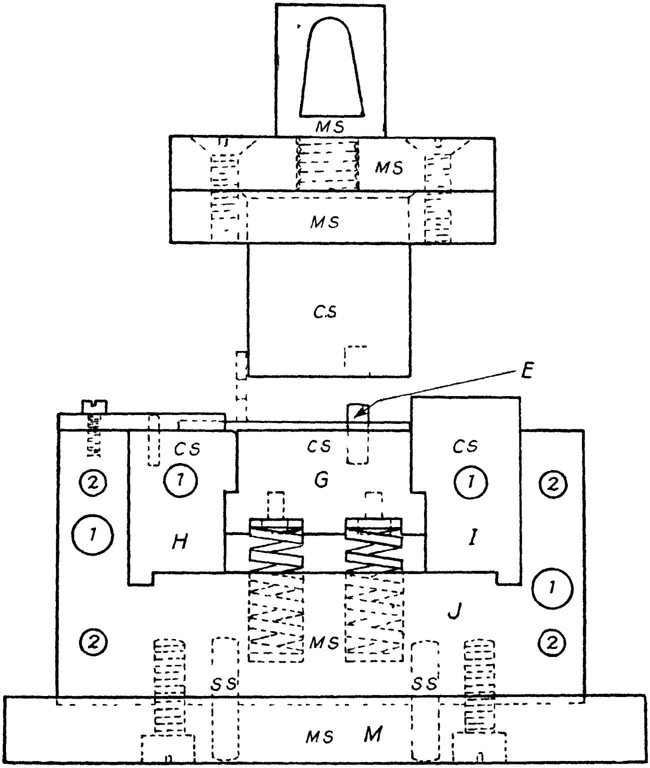


FIG. 8. SPRING PAD BENDING TOOL WITH SIDE PLATE REMOVED

a pierced hole, by means of a pin fixed in the pad *E*. This will allow the hole or holes to be in correct relation to the bend, irrespective of the outside blank size or shape. This is more applicable to the product of a worn blanking tool, which has become somewhat larger through repeated grinding.

VARIOUS TYPES OF SPECIAL TOOLS

A selection of special tools, which usually form part of the tool-maker's kit is shown in Fig. 10. It is advisable to explain that tools of this class are generally made to suit some individual need, and as years go by quite a number of these will have collected. Their uses are briefly as follows.

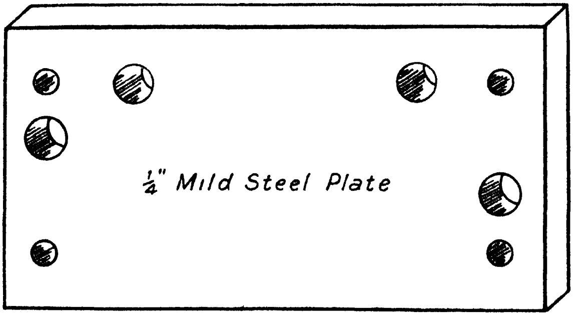


FIG. 9. DETAILS OF SIDE PLATE FOR SPRING BENDING TOOL

Flat Pin Cutter (*A*, Fig. 10). Assuming a hole of ½ in. diameter has to be concentric with a smaller hole, or that a hole has to be counterbored, it is then that the pin cutter is used.

Taper "D" Bit (*B*. Fig. 10). Special sizes in these are required for tapering piercing holes. Taper reamers are often used, but cases will arise when a standard size reamer is not to hand or its size is not suitable. To ensure a correct and true taper it is advisable to use the "D" bit in a slow-speed drilling machine, keeping it well lubricated with soapy water to prevent scouring.

Pin Cutter (*C*, Fig. 10). This pin cutter has much the same uses as that described as *A*, but owing to the toothed formation of the cutting edge, it is not so adaptable for deep work. It is more suitable for forming flat bottom holes or light spot facing of bosses, etc.

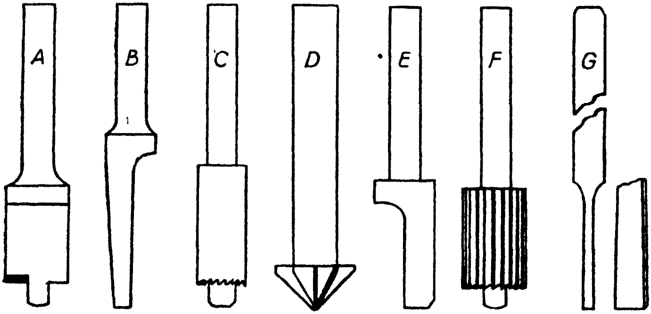


Fig. 10. Various Types of Special Tools

A. Flat pin cutter
B. Taper "D" bit
C. Pin cutter
D. Countersink
E. Parallel "D" bit
F. Rose cutter
G. Drift

Countersink (*D*, Fig. 10). The countersink has too obvious a use to need any explanation, but it is included in this group as a "special" tool that can be made, hardened and tempered by the beginner. Actually, working with this tool will prove whether the hardening, tempering, and final sharpening of the cutting edges are correct—in fact, the above applies to the whole group of tools, and great confidence will be gained if it is proved that they stand up to the test.

Parallel "D" Bit (*E*, Fig. 10). The parallel "D" bit is used to remove the final margin in a given hole, and if properly made can be relied on to "cut size."

Rose Cutter (*F*, Fig. 10). This cutter is in effect the same as *A* and *C*, but having its sides fluted allows for deeper boring without getting clogged up.

Drift (*G*, Fig. 10). This is most useful for drifting out the thin webs of metal that remain between a series of holes when drilling out blank forms, etc. It is used as a chisel, and will require very careful hardening and tempering to stand up to its work.

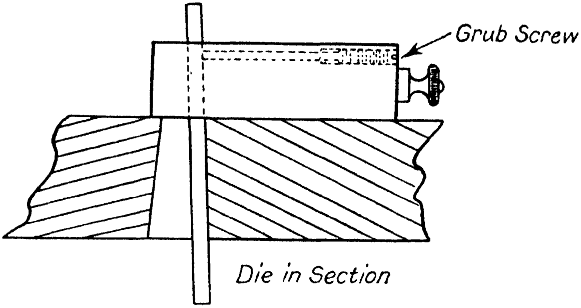
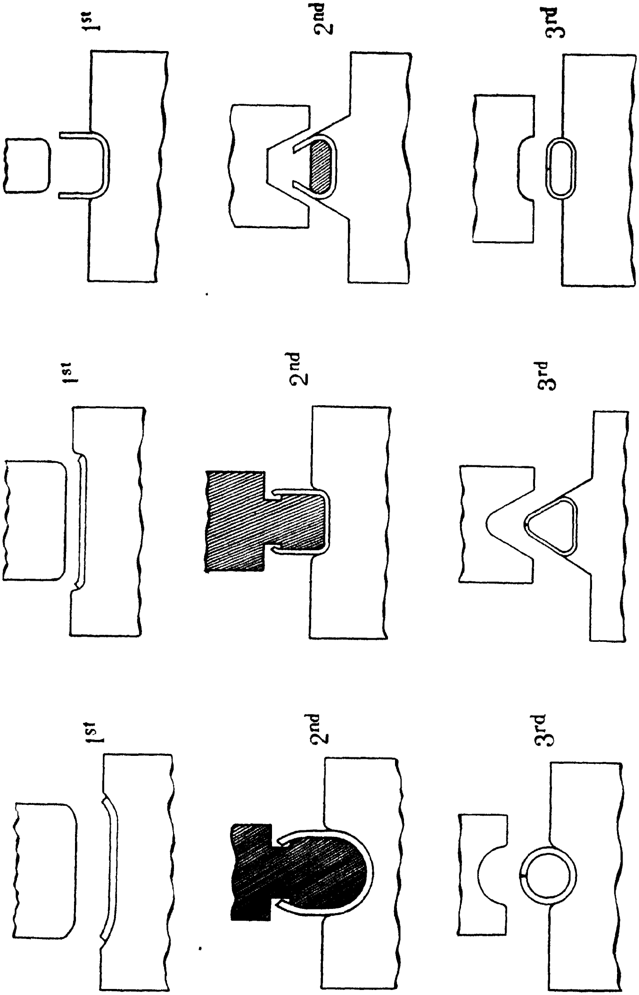


FIG. 11. SHOWING TOOL-MAKER'S SQUARE WITH SMALL BLADE INSERTED, AND ADJUSTED TO AN ANGLE OF 2 DEGREES

Tool-makers' Square (Fig. 11). This tool is essential for checking the degree of taper in small dies. As will be seen, the blade can be adjusted by means of a small grub screw, but, usually, once set to a given angle it is seldom necessary to alter the adjustment. It can of course serve as an ordinary set-square, by using the wider blade supplied, but there are always other squares to hand, so it is advisable to keep this for the one purpose.

BENDING AND FORMING

Many shapes and forms may be accomplished in the press, and it is only a few examples that are illustrated in Figs. 12, 13, and 14. These are all simple



Figs. 12–14. Examples of Press Work

examples and are given to convey the principles employed. In all cases correct registering is important, and the method by which the finished article can be extracted must also be considered. More elaborate examples would call for sprung pads, disappearing

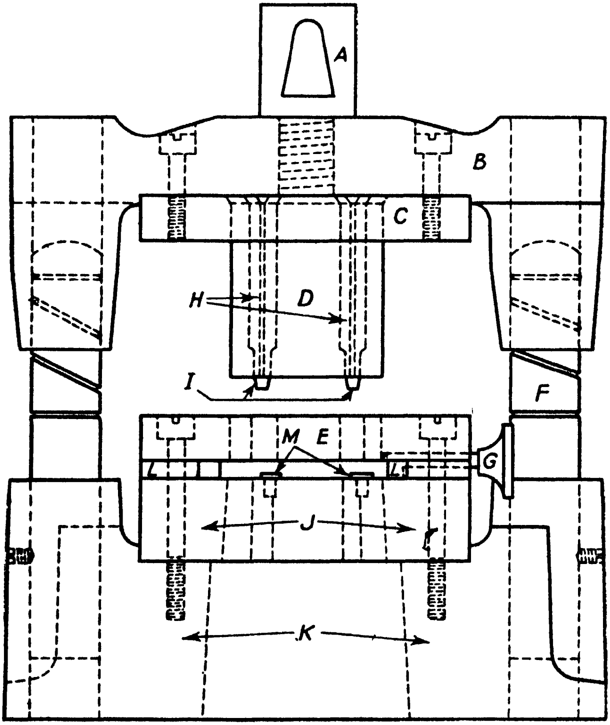


FIG. 15. BLANKING AND PIERCING TOOL

A. Spigot, mild steel
B. Spigot plate casting
C. Punch plate, mild steel
D. Blanking punch, cast steel
E. Stripper plate, mild steel
F. Guide posts, mild steel
G. Side stop, mild steel
H. Piercing punches, silver steel
I. Pilots, silver steel
J. Die cast or combination steel
K. Bolster casting
L. Stripper guides, mild steel
M. End stops, silver steel

register pins, mechanical extraction devices, etc. All these tools, whether simple or advanced, have to be highly polished on the working edges and surfaces,

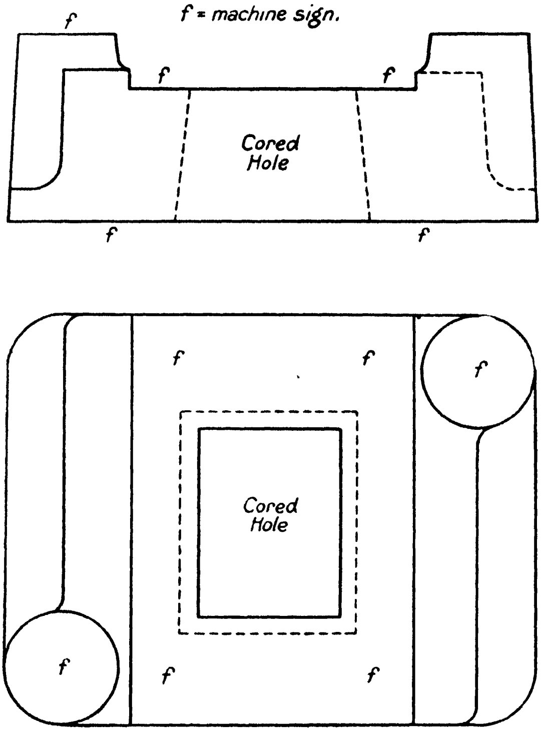


FIG. 16. END VIEW AND PLAN OF CAST BOLSTER

otherwise a rough spot may have the tendency to drag the metal out of alignment, or seriously deface the finished article. It is very difficult to describe any hard and fast rules which govern the particular process, as so much depends upon the nature of the material used and the intricacy of the finished production.

For example, one particular component may have to be formed and the rough surplus edges removed afterwards, another may have to be blanked to correct size before forming, and, again, yet another may require intermediate operations.

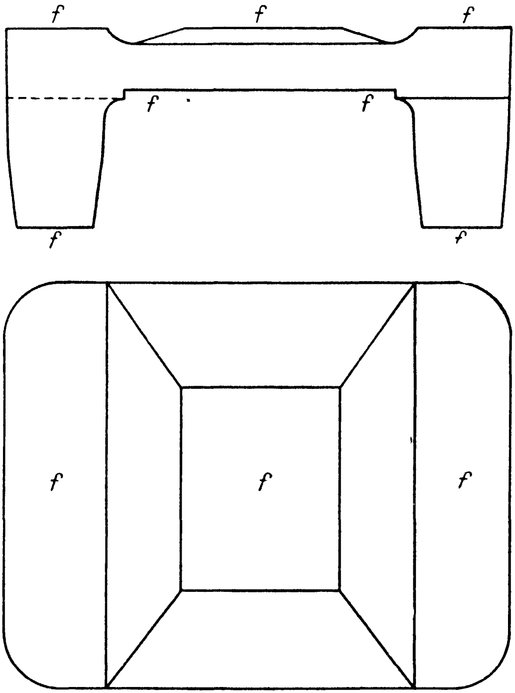


FIG. 16A. SIDE VIEW AND PLAN OF SPIGOT PLATE

BLANKING AND PIERCING TOOL

Fig. 15 shows clearly the main construction and working principles of an ordinary "follow-on" tool, which is designed to produce the same fitting as previously described, but by this method much better-class work results. Although simple in design, it embodies all the principles of a press tool, and can be elaborated as the need arises. Constructed on a cast bolster with two guide posts, the tool is entirely self-setting, which is a big asset in many ways. The component parts will be dealt with in the order in which they should be undertaken.

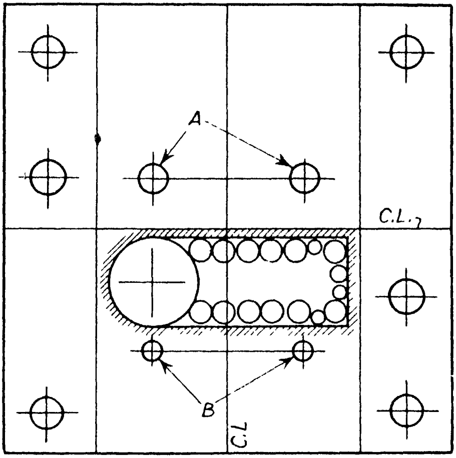


Fig. 17. Die Marked Off Ready for Drilling
A. Piercing holes
B. End stop holes

THE BOLSTER AND SPIGOT PLATE

A casting, not necessarily as drawn, must be designed to accommodate the die housing for the two guide posts, and a ledge by which it can be held down to the bed of the press. A square hole is cored in the middle of the bolster large enough for the piercings and blanks to pass through. The underneath surface and a recess for the die are to be machined (see Fig. 16). The spigot plate is a casting in shape and form resembling the bolster, minus the centre core (see Fig. 16A), which also needs machining. The bolster and spigot plate are now clamped together on a face plate, and the holes for the guide posts bored in the lathe. Also drill and tap the hole into which the spigot screws.

THE DIE

Steel for the die, either cast or combination, is machined and squared up to fit tightly in the bolster register. Clean up the working surface, colour and mark off as shown at Fig. 17. The lay-out of the die must be governed by the amount of scrap between the blanks, in this case ⅛ in. Drill out the main blanking die and file to the finished size, backing off at two degrees. In some instances it is advisable to file a profile gauge to work to, which is a piece of plate dead to size and shape. Should this be of such size that it is impossible to hold in the die, it can be fastened to a piece of wire or a bicycle spoke by drilling a hole through the gauge and securing by two nuts (see Fig. 17A). All holes may be drilled in the die and the piercing holes backed off. Harden, temper, and grind. Clamp the stripper guides (see *L*, Fig. 15) in position, leaving

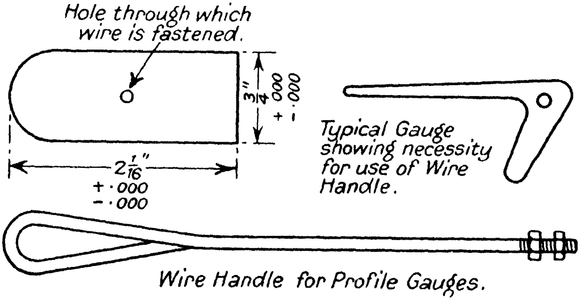

Hole through which wire is fastened.
3/4"
+·000
-·000
2 1/16"
+·000
-·000
Typical Gauge showing necessity for use of Wire Handle.
Wire Handle for Profile Gauges.

FIG. 17A. PROFILE GAUGE

⅛ in. scrap on the sides of the blank, and drill the screw and dowel holes from the back of the die.

THE MAIN PUNCH

(See Fig. 18.) Mark off the punch and machine as near as possible to the finished size, afterwards filing and shearing through the die. When to size, set up and mark off the drilling centres for the pilots (see *1*, Fig. 15). As the name implies, these pilot the strip metal to a definite position before blanking, by entering the pierced holes. Although end stops are fitted to determine the length of travel, they only give an approximate setting, to be adjusted by the taper of the pilot. These pilot holes are drilled right through, and countersunk on the back edge. Harden, temper, and stone the punch to a nice fit in the die.

THE STRIPPER

Mark out the stripper from the die and prepare the main punch hole, until it is possible for the punch to be driven through easily. Register the stripper on the die by means of the punch, and drill all the holes (Fig. 18A).

SIDE STOP

Temporarily assemble the stripper, stripper guides, and die by the aid of four bolts and nuts, and mark off the position for the side stop drilling. This side stop, as will be readily seen, decides the first position of the strip. The designs for stops are varied, some being very elaborate, others just a piece of wire passing through a hole. but the design chosen is both simple and effective (see Fig. 18B). The idea of the stop is to allow the metal strip to come in contact with the blanking punch, at the same time causing no damage to the pilots, therefore a line is scribed ⅛ in. below the back edge of the blank, which will be the determined position. Carry this line over the right-hand side of the die, and

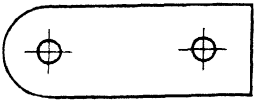


FIG. 18

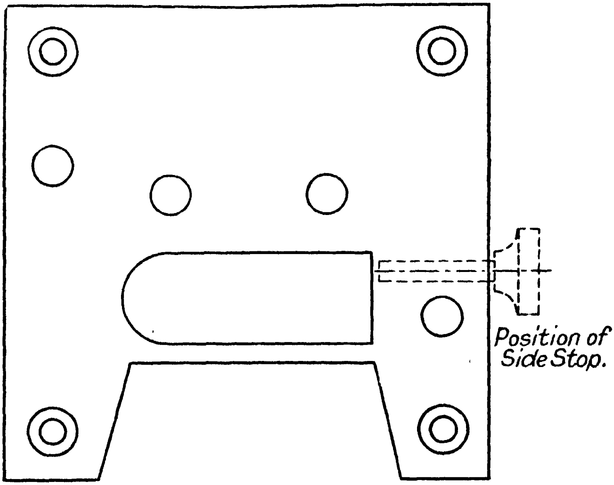


FIG 18A. PLAN OF STRIPPER PLATE

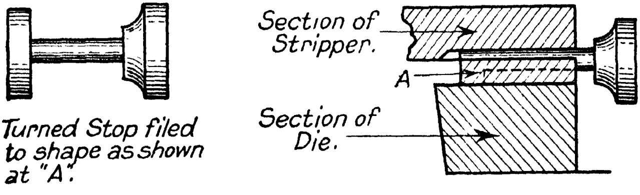


FIG. 18B

$\frac{1}{8}$ in. below scribe another line, this being the centre for drilling. As will be seen by the sketch, it is so designed that half the hole is in the stripper and half in the stripper guide, which makes it possible to have the stop turned in one solid piece.

TURNING

All turning can be done, the sizes for which are determined by the drilling. Should the work be given to a turner, a sheet should be prepared giving the sizes required, as shown at Fig. 19.

PUNCH AND SPIGOT PLATE

The punches may be fitted to the punch plate. To determine the definite position for this, assemble the die portion and guide posts. Insert the punches with punch plate intact through the stripper into the die. Between the stripper and punch plate a pair of parallel strips must be used for packing, to prevent the punches entering too far into the die. Making sure this assembly is flat and solid, place the spigot plate in position, and drill and tap through into the punch plate. For further safety two dowels may be fitted.

FINAL ASSEMBLY

The whole tool is now dismantled for final assembly. Grub screw the guide posts to prevent them lifting. Fit the end stops in the die, and assemble the bottom portion permanently. Insert the pilots, and rivet the back ends over. Screw the spigot tightly in the spigot plate, and screw and dowel the spigot plate to the punch plate to complete the top portion. Grease all working parts, and assemble the top and bottom units. It is the practice in some shops to mark the tool, by the aid of steel stamps, with the drawing and part numbers in a conspicuous place. Try out the tool, and make any necessary adjustment on the pilots, side, or end stops.

BLANK TOOL WITH SPRING STRIPPER

Up to this point tools have been described that are suitable only for production of heavy gauge blanks, therefore it is deemed advisable to point out that the thickness of metal or material needed is a decisive point with regard to the type of tool to be constructed. In order that the value of this may be appreciated, we will depart from the previously mentioned 12 " B.G." plate to a paper fitting of the same shape and size—0·012 in. thickness. The construction and action of this spring tool is decidedly reverse to that of the ordinary blanking tool, inasmuch as the punch is fitted to the bottom portion, and the blanks, instead of passing through the die, are pushed back into the strip, to fall

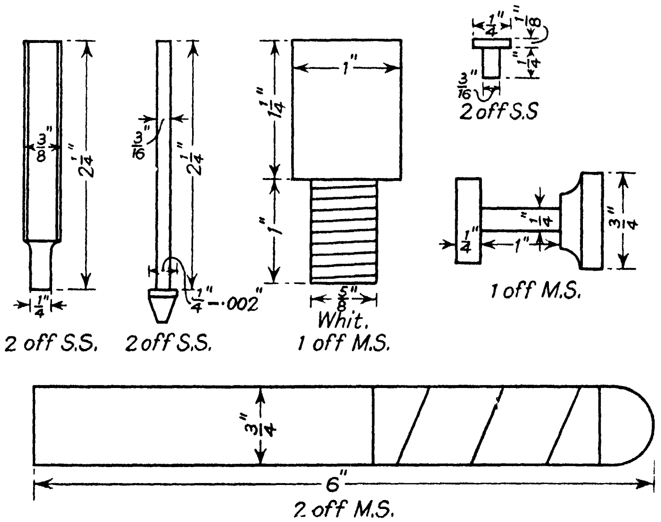


FIG. 19. SIZES OF TURNED COMPONENTS

away as the strip is fed through. The general construction of this tool is shown in section at Fig. 20, which clearly explains the working principles. It can be designed either square or round, to suit the individual job it may be required to do. For instance, for producing round paper or fibre washers, much labour and material is saved by encasing in a round body, large enough to accommodate a series of springs placed round the main punch. Again, it may be so constructed as to fit on a similar bolster to the one used in the preceding description.

THE PUNCH

In this case the punch is the first unit to receive attention (see *D*, Fig. 20). A piece of cast steel of sufficient size is cut off and machined up square, when it is coloured and the blank size marked off. File up to the finished size, from which the correct centres for the piercing holes are determined with the height gauge. Drill these right through and back off with a " D " bit or taper reamer.

BASE PLATE

If no bolster is being used, the base plate must be somewhat substantial in thickness as it has to be recessed to register the punch, also the outer casing (see *A*, Fig. 20). Machine a piece of mild steel for this large enough to extend 1 in. each side of the outer casing for holding-down purposes. Plan out the best position for the punch and mark out the recess to accommodate it, also the recess for the outer casing, both of which may be milled at the same setting. These need only be about $\frac{1}{16}$ in. deep. Take great care that this milling is such that it forms a definite register for their component parts, otherwise they are useless. Fit the punch in its correct position, and from the

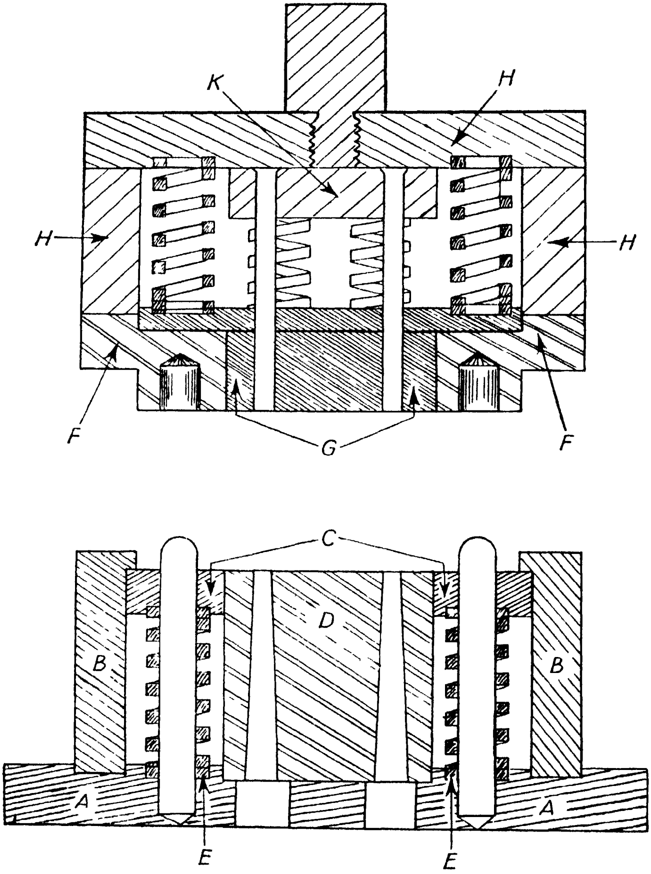


FIG. 20. BLANKING TOOL WITH SPRING STRIPPER
(Top and bottom portions)

bottom of the base plate drill and tap a number of holes to accommodate the screws which hold the two parts together. These, of course, must be so spaced as not to break into the piercing holes. If space permits, for additional safety fit at least two dowel pins. With the punch temporarily screwed to the base plate, drill the piercing holes right through, and on dismantling open out to at least the backed-off diameter.

SPRING STRIPPER

A piece of ½ in. bright mild steel is heavy enough for this unit, the outside of which must be determined by the number and size of springs that are intended to be used (see *C*, Fig. 20). This must be a somewhat easier sliding fit over the punch than the ordinary fixed stripper, and in the event of any tightness or binding occurring the springs would refuse to function. Mark off the stripper and drill the centre away, and at this stage harden, temper, and grind the punch, so that it is in readiness for shearing through the stripper. Having done this, ease with fine files, until the desired sliding fit is obtained.

SPRINGS AND SPRING HOUSINGS

A number of suitable springs must be selected, and preparations made for housing them (see *E*, Fig. 20). This can be done either by fixing small spigots in convenient places for the springs to fit over, or by counterboring with a flat-bottom bit, large enough to suit the outside diameter.

OUTSIDE CASING

The outside casing has its manifold uses according to its construction (see *B*, Fig. 20). If constructed completely round or square it acts as a grease retainer, and a protection against dirt and grit coming into contact with the working parts. As drawn, namely, a plate each side, it is holding the stripper in place, and in either case acts as a register or housing for register pins. For setting up purposes, whichever principles are embodied, it must be firmly registered in and screwed to the base plate.

THE DIE

This may be of cast steel 1 in. thick, and in size following that of the stripper (see *F*, Fig. 20). As will be remembered, springs determined the size of this, so will similar springs need housing in the top portion. Unlike the ordinary blanking die, this must be kept parallel all the way through, to allow a spring pad to operate. Reference to this will be made shortly. File out the die to a nice fit on the punch. After drilling holes practical in number and size for fixing to the top outer casing, the die may be hardened, tempered, and ground.

SPRING PAD

A piece of mild steel (*G*, Fig. 20) forms the pad. This is made an easy sliding fit in the die, and fastened to a back plate of $\frac{3}{8}$ in. mild steel against which the springs operate. Insert the pad in the back of the die, and between the plate and die place two metal strips about $\frac{1}{16}$ in. thick. In an inverted position, using the back plate as the base, insert the punch for the purpose of drilling the piercing holes through the pad.

TOP OUTER CASING

In planning the top casing, the outer size is governed by the die, and the inner by the amount of movement required and the springs being used. The bottom portion is usually a good guide for determining this, and should bear somewhat similar proportions (see *H*, Fig. 20).

THE PUNCH PLATE

Inside the outer casing, fixed to the top, is the punch plate (see *K*, Fig. 20). The punches are fixed to this in the usual way, and their respective positions are transferred from the pad when temporarily assembled in the die.

SPRINGS AND SPRING HOUSINGS

(Top portion.) The same exactly applies to the arrangements previously made in the bottom portion.

ASSEMBLY

End stop pins have to be fitted to the stripper, but must be of the plunger type, as shown at Fig. 21, in order to disappear as the die comes down. Register pins or guide posts may be fitted to assist alignment when setting up. The whole can be finally assembled and dowelled, allowing a liberal supply of grease on all working parts. In case the advantages of this type of tool have not been fully grasped, it might be added that a true flat blank must result, and with any amount of grinding the blank still retains its limits. This tool may be specially recommended for thin metal, paper, cardboard, fibre, leather, press-pahn, and any similar material.

Having described various tools in their simplest form, both in lay-out and construction, it is now opportune to impress how important is the actual lay-out of certain fittings, to minimize scrap, and, incidentally, cost of production. Suitable material can be purchased at market prices, but when it comes to disposing of the scrap, great depreciation of price occurs, therefore it is up to the tool-maker or designer to plan his die to the best advantage. For purpose of illustration, Fig. 22 will be dwelt upon in detail. This is termed a " turnover " or " return tool," as the strip is passed through in the usual manner and then returned. Additional

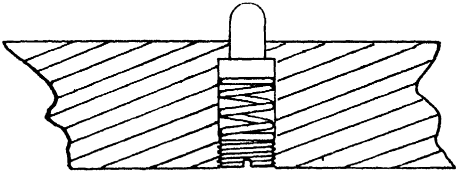


FIG. 21. ENLARGED SECTION OF SPRING STOP

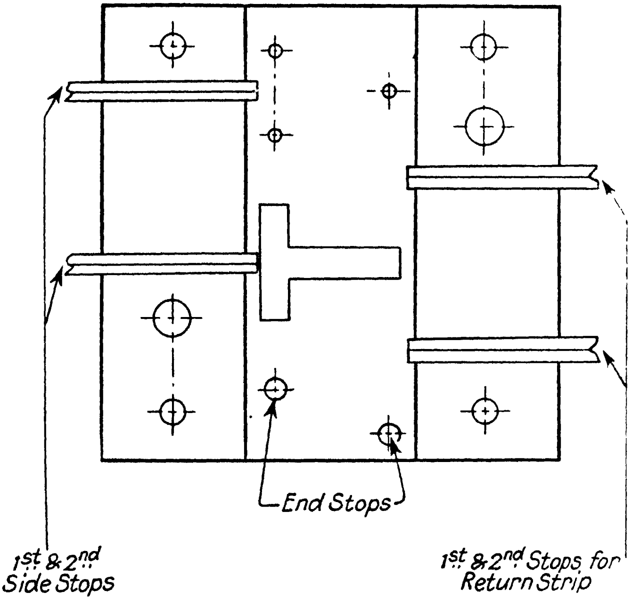


FIG. 22. LAY-OUT OF DIE FOR RETURN TOOL

side stops are fitted to adjust the return starting position, but eventually the end stop comes into operation.

THE LAY-OUT OF THE DIE

Whether the blanking required is identical or similar to that shown in Fig. 23, great thought and care must be exercised in the calculations of the lay-out. The example shown must be accepted as a typical blanking needing a return tool, and in no way must it be considered as a standard. Each individual fitting requires individual thought. Here again a die 4 in. square and 1 in. thick is of sufficient size, and can be fitted to a cast bolster, following in construction exactly those previously described. On paper or sheet brass draw a number of fittings in order to leave $\frac{3}{32}$ in. scrap between each (Fig. 24). This experiment determines the length of travel, and allowing $\frac{3}{32}$ in. each side gives the width

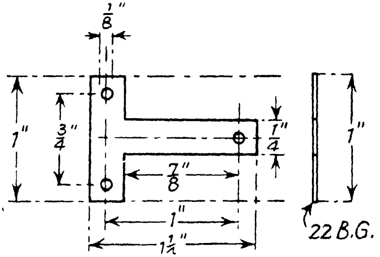


FIG. 23. DETAILS OF REQUIRED BLANK

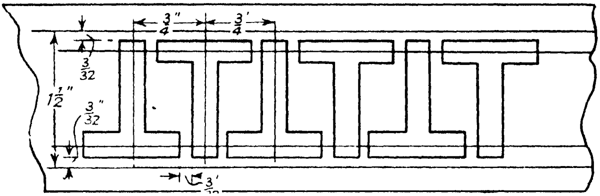


FIG. 24. EXPERIMENTAL LAY-OUT OF BLANKS ON SHEET BRASS

of strip necessary. Square the die, and prepare it to receive the markings. Packed up to a convenient height on parallels, with the aid of the height gauge transfer the centres already determined by the previous experiment. The positions for the stops are best marked on the face of the stripper when it is bolted to the die, ready for drilling, the position of which in relation to each other is the same as the travel from centre to centre of the blanks. As an alternative to the turnover tool, two sets of punches may be arranged, causing a similar effect, but quicker in production. The layout of the die will take the form as shown in Fig. 25.

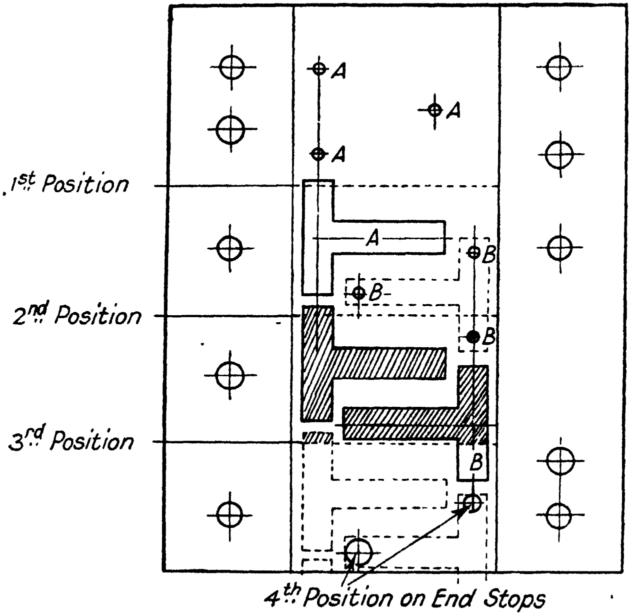


FIG. 25. BLANKING AND PIERCING TOOL WITH DOUBLE SETS OF PUNCHES *A* AND *B*

Extra length of die must be allowed for the double blank, which needs careful spacing out before commencing actual work.

SECTIONAL DIES

Fig. 26 shows a fitting which calls for a sectional or built-up die. As will be readily seen, even if possible, it would be a terribly tedious task backing out a die of this description from the solid steel, therefore it is advisable to design a die built up in sections, as shown in Fig. 26A, again allowing for a return of the strip. No detailed description of this is needed, other than to stress the importance of adding extra dowels to ensure against any displacement of the sections occurring. An inserted die is usually designed for the purpose of exercising economy. It must be understood that, however

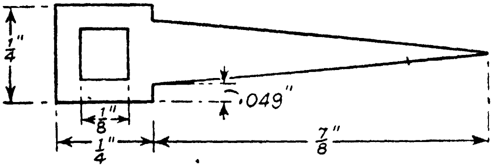


FIG. 26. TYPICAL BLANK NEEDING SECTIONAL DIE

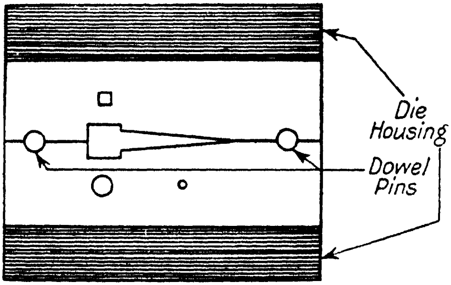


FIG. 26A. SHOWING SECTIONAL DIE IN ITS HOUSING

small the fitting required, the tool to produce it must be of such size as to suit the requirements of the press, therefore, to save cutting up cast steel to waste, mild steel is used as a housing for the die. The housing is formed either by milling a slot right across (see Fig. 27), or counterboring to suit a round die. This class of die is especially applicable to small piercings or blankings, examples of which are clearly shown at Figs. 26, 26A, 28. Referring to the making of the latter, the two halves must be held in a four-jaw chuck and turned together, and in no case must a solid disc be turned and then split.

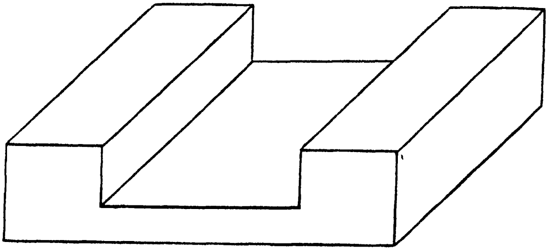


FIG. 27. MILD STEEL BOLSTER

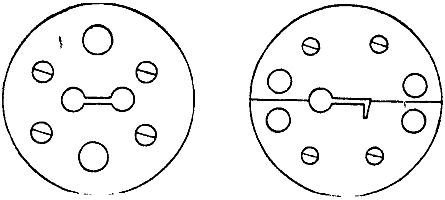


FIG. 28. LEFT, INSERT DIE, AND, RIGHT, SECTIONAL INSERT DIE

SPECIAL LAY-OUT OF FOLLOW-ON TOOL

At first sight fittings such as those shown in Fig. 29 would appear to present no difficulty to the beginner, but on careful thought and inspection it will be seen how delicate both the punch and die would be if the principles of the ordinary follow-on blank and piercing tool were adopted. Apart from being awkward to make, the punches would present a very difficult proposition for hardening. According to the class of steel used, displacement of metal or fractures would be likely to occur. The dies would also create anxiety, not only during hardening, but in actual use, owing to the uncertainty of the thin extending tongue of metal being strong enough to withstand the blow; therefore, with all these anxious moments, and probably wasted time, the designer or maker would be well advised to follow on the lines of those shown at Fig. 29. To explain clearly the exact principles embodied, strips are shown having received the blow of the piercing and blanking punches. The shaded portions show the metal which was removed while the strips were in their primary positions. In many instances this tip will be found useful, perhaps resulting in more scrap metal than usual, but that, balanced against the cost of making another tool, will be found, in these cases, negligible.

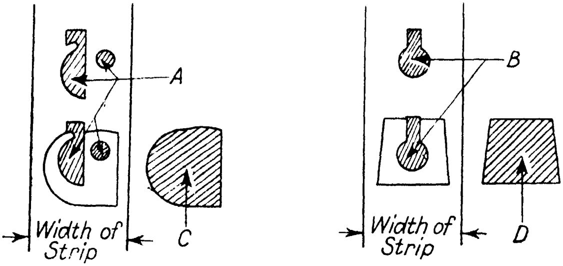


FIG. 29. SHOWING TWO EXAMPLES OF SPECIAL LAY-OUTS

Shaded portions *A* and *B* represent piercings
Shaded portions *C* and *D* represent sections of blanking punches

SIDE PIERCING TOOL

For description of this we will assume a cup has has been drawn 4 in. in diameter, with sides 1 in. deep in 22 " B.G." metal, and it is necessary to pierce half a dozen ¼ in. holes, equally spaced around its wall. It would be unpractical and impossible to pierce these before forming, for the displacement of metal occurring during the forming operation would seriously distort any piercings. Here again is a case for thought, for although the same principles are embodied, the mind has to be adapted to deal with the individual requirements. There are two ways in which this operation can be carried out in simple form, the one, by mounting the formed cup on a steel disc, standing at right angles to the bed of the press, piercing one hole and registering off that hole for the next position until the six are completed (Fig. 40 gives an idea of the construction); or the other, which is recommended, as shown at Fig. 30. This is drawn in section and is practically self-explanatory, although a few notes will be helpful. As will be seen, the die is composed of a turned ring to fit the form of the drawn cup. This may be of mild steel, with cast steel bushes equally spaced, but before drilling for these it is advisable to mark off and drill the holes in the punch housing, which, if correct, can then be transferred to the die. As the hardened bevelled surfaces of the punches fitted in the top portion come into contact with the actual piercing punches, so they are depressed, to be returned on the upstroke to their original position by means of springs. The idea of the whole construction can be elaborated as the occasion arises, but at the same time adhering to the main principles.

BLANKING FORMED FITTINGS

There are times when it is impossible to determine the blank size of a formed fitting, and it is then that

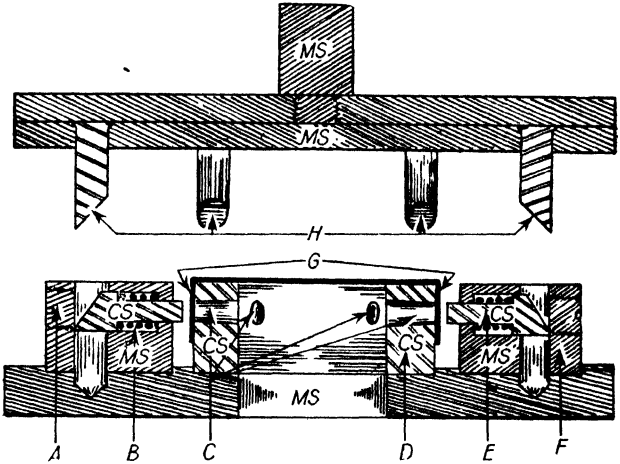


FIG. 30. SECTIONAL VIEW OF SIDE PIERCING TOOL

A.	Retaining screw	*E*.	Piercing punches
B.	Springs	*F*.	Punch housing
C.	Piercing holes	*G*.	Formed cup
D.	Die	*H*.	Cast steel operating punches

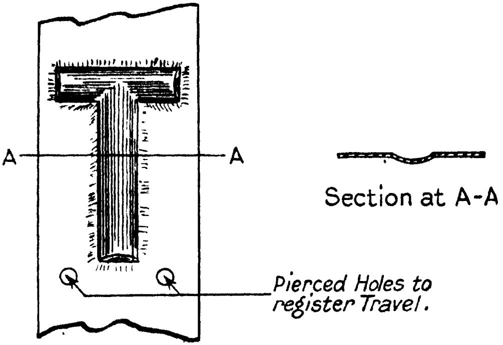


FIG. 31. EMBOSSED FITTING IN STRIP

the blanking has to be accomplished after forming. For example the letter "T" is taken, formed in half round section, in a strip of metal (see Fig. 31). The forming is done in a punch and die, and the travel distance regulated by pins, as in the case of a blanking die. To ensure a definite register two piercing holes may be introduced, which will also prove very useful during the blanking process. For blanking, a punch and die are designed to conform with the outside edge of the embossed form. This will be fitted with a stripper, corresponding in every way with the ordinary blanking tool. To operate, pass the formed strip through the stripper guides, registering for each blank, by such means as provided. This idea is often applicable to fittings taking the form of an irregular draw, where it is difficult or impossible to blank first.

OPEN DIES WITH SPRING STRIPPERS

Often circumstances arise, in blankings of a larger nature than those already referred to, where it is impracticable to combine the piercings. Also many blanks have to be bent before they are pierced, and it is in these two cases that the open type tool described in Fig. 32 is useful. As a typical example, the blank to be pierced after bending will be considered. Assuming the centres shown in Fig. 33 to be important, it would be very unwise to incorporate the piercings with the blanking operation. A certain displacement of metal occurs in bending which cannot be standardized owing to the varied nature of metals, also the extent to which the fitting is planished, therefore it will be seen that, once this displacement has occurred, a die can be made that will form a definite register and ensure piercing to a very fine limit. The main principles differ very little from the tools already described, but a comment on the general construction will be found helpful. The lower portion of die is built up of mild steel with cast steel bushes inserted. In designing this unit allowance must be made for grinding, and in grinding care must be exercised to maintain the existing relation between the two working surfaces. Provision must be made for housing two register pins or guide posts, which are fixed in the punch plate, passing through the spring stripper. The upper or punch portion comprises the stripper, punch, and spigot plates, 4 screws and

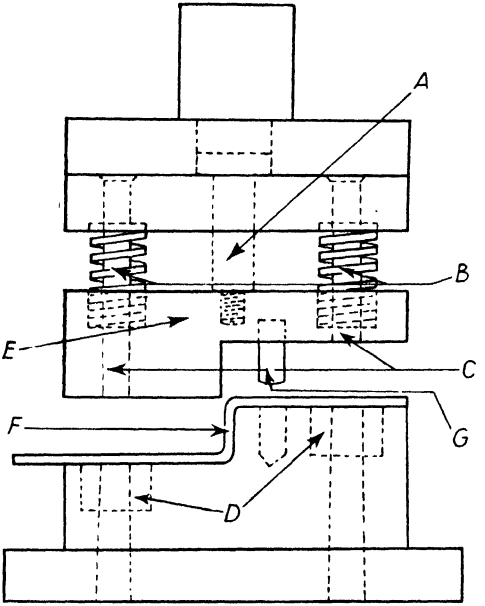


FIG. 32

- *A*. Special turned assembly screws
- *B*. Springs
- *C*. Piercing punches
- *D*. Cast insert bushes
- *E*. Formed stripper
- *F*. Formed blank
- *G*. Guide pin

springs, and 2 guide pins. The under edge of the stripper takes the form of the bent blank. Not only does this act as a guide for the punches, but it extracts the fittings after they are pierced. A study of Fig. 32 will suffice for any information that may be required for the construction of this unit.

DRAW PLATE TOOL

While on the subject of handling individual blankings for a second operation, details of a draw plate tool

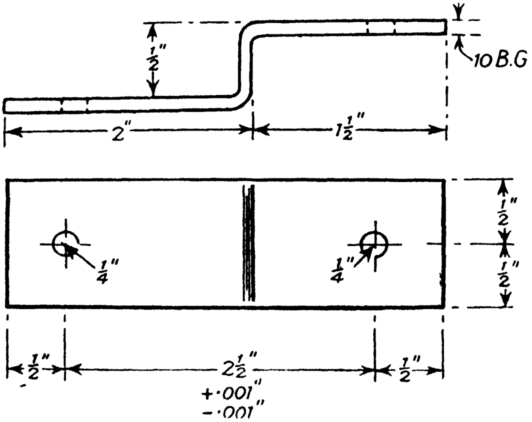


Fig. 33. Details of Formed Blank to be Pierced

will be of interest. There are times when it is exceedingly risky for the operator to place the blanking in a die for further operations, by means of the fingers, and it is for this reason that the draw plate tool, such as shown at Fig. 34, is designed. For the purpose of illustration we will take in hand a number of round piercings of 16 B.G. steel 1 in. in diameter, which are really the scrap from another tool, and it is intended to utilize these by piercing a ¼ in. hole in the centre for washers.

The scrap piercings are placed in a receptacle of the draw plate, which is then pushed in to a definite stop. After the press has completed its stroke the draw plate is withdrawn, the washer removed, and another blank (1 in. diameter scrap piercing) inserted. With this type of tool the operator has to be careful not to put the press in action until the draw plate is in its correct position, otherwise serious damage may result.

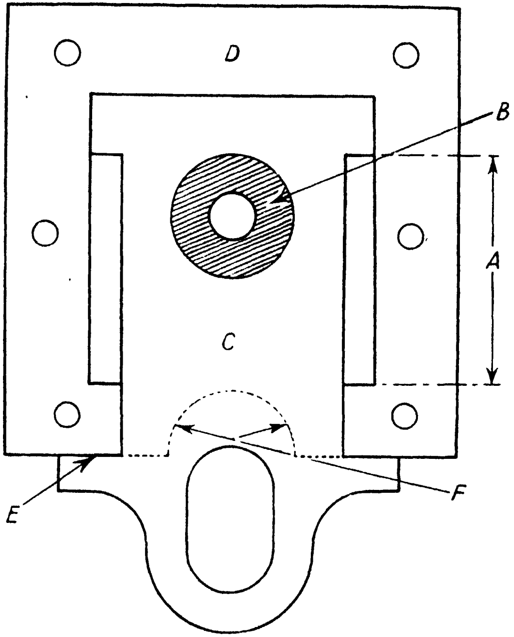


Fig. 34. Draw Plate Tool with Stripper Removed

Showing washer pierced ready to be withdrawn

A.	Length of travel	*D*.	Packing plate
B.	Washer	*E*.	Visible position stop
C.	Draw plate	*F*.	Clearance in die to allow washer to drop

TWO NOVEL USES FOR THE DRILLING MACHINE

Difficulty is often experienced in reducing a thin pilot stem or the like, and the following hint will prove useful. In a piece of $\frac{1}{8}$ in. plate, drill a hole in which the stem will freely revolve. Hold the pilot by its head in the drill chuck, and clamp the plate in such a position as to support the back end on the drill table. Adjust the table so as not to cause binding, and the work can be rubbed down quite easily and true with a smooth file. It is common knowledge that the drilling machine is often used for rounding the ends of dowel pins, etc., but for obtaining a true flat end, such as could be done in a lathe, it is not quite so well known. Of course this is only applicable to work of a small nature, such as the faces of end stops or pins. Secure the work in the chuck, and hold a superfine flat file on the table. Gradually bring the work down in contact with this, and in a very short space of time the desired effect will result.

NECESSARY TOOLS AND OPERATIONS FOR A CANDLE SHADE HOLDER

By way of further instructions, the introduction of other simple orthodox tools needed for the entire production of an article of commercial value will be explained in detail, namely, a brass candle shade holder, such as used on piano brackets, and as drawn at Fig. 35. Perhaps it would be of interest to point out here that, although the cost of these holders is only the matter of a few pence, the cost of tools for production, plus running expenses and overhead charges, is enormous; therefore it will appear more striking to the tool-maker, or designer that the method of production must be thoroughly worked out, and the scrap reduced to a minimum. It is not to be supposed that the improver will be held in any way responsible for these details at present, but, nevertheless, these facts must be constantly in one's mind, and will prove more valuable as time goes on.

THE SHADE SUPPORT

We will assume a blue print giving details of the assembled article, or a sample holder, has been submitted, and that it has been decided to concentrate on the shade support *A*, Fig. 35. Owing to the shape of the form, an ordinary spring tool may be designed, but in the event of a deep cup being needed, tools for a double-action or toggle press would be required, knowledge of which will be gained as experience grows. The disadvantage of the spring drawing tool, as described, for deep drawing, is that the nearer the press to the finish of the stroke, the harder the pressure becomes, increasing until it is impossible for the metal to pass through into the drawing die, obviously resulting in burst metal, but in the case of a double-action or toggle press, even pressure can be assured and adjusted, to allow the metal to pass into the die evenly. In order to see at

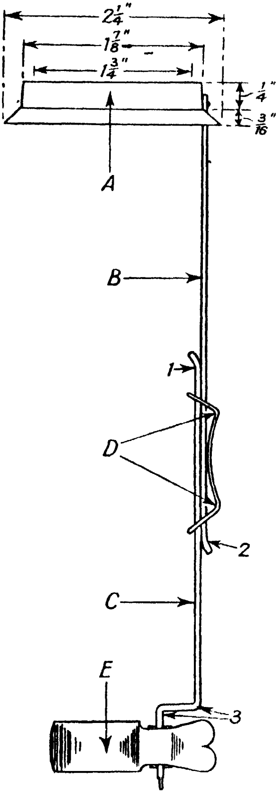


Fig. 35. General Details of Candle Shade Holder

A. Shade support
B. Support arm upper
C. Support arm lower
D. Centre cup clip
E. Spring clip

a glance the working principles of this spring drawing tool, a sectional drawing is given at Fig. 36. To ensure

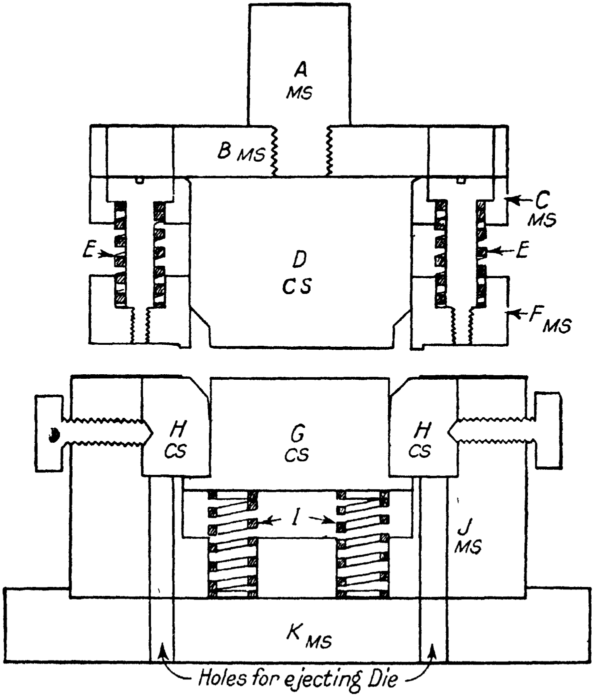


FIG. 36. SECTIONAL DRAWING OF SPRING FORMING TOOL

A. Spigot
B. Spigot plate
C. Punch plate
D. Punch
E. Springs
F. Spring stripper
G. Spring pad
H. Die
I. Springs
J. Housing
K. Base plate

faithful reproductions, either from the drawing or sample, male and female profile gauges will have to be made, which will take the form of those shown in

Fig. 37. As the largest diameter of the shade support is 2¼ in., a piece of cast steel, 3 in. long × 2½ in. diameter, is needed for the punch. This must be turned in the lathe to the finished size, using front and back centres for resetting purposes. Rough turn the working end until the form appears in its crude shape, then by more careful turning and constant checking with the gauge *A*, produce a faithful reproduction of the desired shape, at which time it should present a smooth surface, free from all machine marks. The punch can now be placed in a chuck, and the back end faced down until it is approximately 2¼ in. long. Recess this end about $\frac{1}{32}$ in. deep to within $\frac{1}{16}$ in. of the outer edge, leaving a thin wall which can be easily riveted over when fixing in the punch plate.

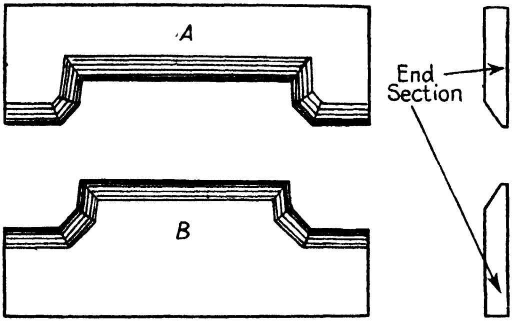


Fig. 37. Male and Female Gauges

THE DIE

Satisfied with the form and finished surface of the punch, the die can be taken in hand. This can be of cast steel inserted in a mild steel bolster of rather heavy proportion, to withstand against any expansion that is likely to occur. A piece of cast steel turned, 3¼ in. diameter × 1 in. thick, is suitable for the die. Fix firmly in a chuck, bore out the centre to 1⅞ in. diameter. In turning the form, great care must be exercised. This must follow the punch (plus thickness of metal) in every detail, and can only be achieved by constant checking with the punch and strips of metal of the required gauge. It must be impressed that the actual relation of the two forms cannot be definitely arrived at until the tool is assembled in the press under actual working conditions. Any variation or irregularity of form will then present itself, and for this reason it is advisable to leave punch and die soft, for further necessary adjustment.

SPRING PAD

This will be of cast steel, turned to sliding fit in the bore of the die, with a flange to prevent its being displaced by the springs. A great amount of springs will not be needed, as the form is tapering and shows no tendency to stick in any way. For even pressure make accommodation for three or four springs to be housed in the bolster.

BOLSTER

Allowing ⅞ in. all round the die brings the diameter of the bolster to 5 in., therefore a piece of mild steel 2½ in. × 5 in. diameter is needed. Counterbore this out 1 in. deep to admit the die as a tight fit, and at the same setting bore to accommodate the flange diameter of the spring pad. The depth of this will be determined by the depth of travel needed, plus the thickness of the flange, resulting in the pad forming a solid base at the finish of the stroke. In such a position as not to interfere with screws or dowels, drill two ⅜ in. holes through the bolster and, eventually, the base plate.

As the die has to be a drive-in fit, without these holes it would be an impossibility to remove it when required, but by making this provision, pins may be inserted and the die driven out of its tight housing. Smear the edge of the die with oil or grease to prevent scouring or binding, and force it down to its seating. Whilst in this position, space out and drill a series of $\frac{3}{8}$ in. Whit. tapping holes to accommodate the holding screws, which are tapped after the die has been removed, but before removing make some mark to denote the position for re-assembly.

BASE PLATE

This can be anything of a suitable size and nature, machined perfectly flat, and a register turned to admit the outside diameter of the bolster to which it is screwed and dowelled in the usual way.

SPRING STRIPPER

For neatness in design, also to afford ample accommodation for the springs, the diameter of the stripper will follow that of the bolster, namely, 5 in. Cut off a piece of $\frac{5}{8}$ in. mild steel plate 6 in. square, and in the power saw cut off each corner, leaving it octagonal in shape. Mount this up in an independent four-jaw chuck for facing and boring, and turning the outside edge. When reversed, check the centre bore with a test indicator fixed to the arm of the scribing block, and with inside calipers check the distance in various places from the face of the chuck for parallel. The result should be subject to a micrometer test, and if not satisfactory must be finished off on the grinder. Holes can be drilled at regular intervals for the screws, the stems of which are designed to pass through the bore of the springs.

There will need to be six or eight of these, according to size and strength, to ensure uniform pressure.

PUNCH AND SPIGOT PLATE

In size, these compare with the stripper, and the assembly exactly follows the description of previous examples. After testing and rectifying any irregularities in the shape of the forms, the punch and die can be hardened and tempered and finally assembled. The production will take the form of a shallow cup, which requires the bottom to be pierced out. The blank size of this draw can only be arrived at by experiment, namely, by cutting various discs, until the correct size is found.

THE BLANKING DIE

There is no need to dwell on this tool, as it takes the form of a simple punch and die of the usual design, but the one point worthy of mention is the perfect fit that is required, owing to the thin metal to be blanked. This desired fit can only be obtained by leaving the die a shade under size, and the punch a shade full (approximately 0·005 in each case), to be ground to size on a universal grinder after the hardening and tempering has been done. This must be strictly adhered to, otherwise a rough blank will result, or, even worse, a drawn, instead of a clean-cut, edge.

PIERCING TOOLS

To complete this top unit, three piercing tools are needed, namely, the centre piercing, the slot for the support arm to pass through, and the rivet hole. The two last-mentioned are minute items, but will have to go through the same procedure as a large or complicated operation. The centre piercing is done on a flat die with a formed register screwed on. By this means it is possible to grind the face of the die, without losing the correct setting for the cup. The piercing punch has a spring stripper turned to the desired form, which not only extracts the fittings from the punch, but prevents any distortion taking place during piercing. The complete construction is shown in section at Fig. 38. The piercing through which the support arm passes presents more difficulty than at first is expected. The operation itself is quite a light one, and can be designed

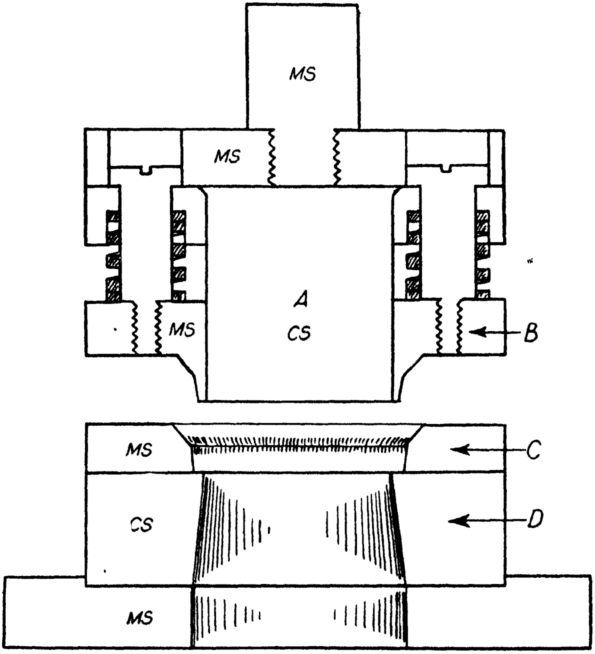


FIG. 38. SECTION OF PIERCING TOOL

A. Punch
B. Formed stripper
C. Movable register
D. Die

for the hand press, taking the form of that shown in Fig. 39. Fig. 40 shows the method employed for piercing the rivet hole. The actual die portion is of cast steel, which is tightly housed before the form is turned. By this means it is much easier to back off the piercing hole, and to arrange a clear passage through which the piercings have to pass. The support arms *B* and *C*, Fig. 35, are made from stock metal cut to length by a tool as described in Fig. 41, and the rivet hole of the top arm *B*, Fig. 35, pierced in a tool of simple orthodox design. The bends (1) and (2), Fig. 35, can also be undertaken in a tool, following the construction of those already described, which needs to be quite light and suitable for the hand press.

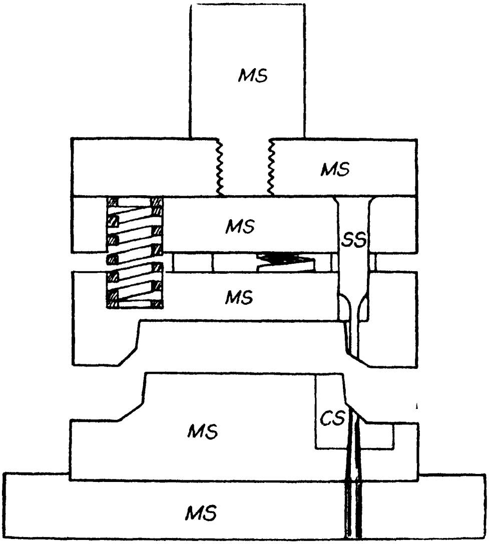


FIG. 39. SECTION OF PIERCING TOOL WITH CAST STEEL INSERT

CENTRE CLIP

The centre clip *D* is produced from a follow-on blank and piercing tool, and calls for no further detail. For bending, a tool embodying the principles shown at Fig. 42 is recommended, namely, a solid formed punch and die, with the blanking registered on the ends by two register plates.

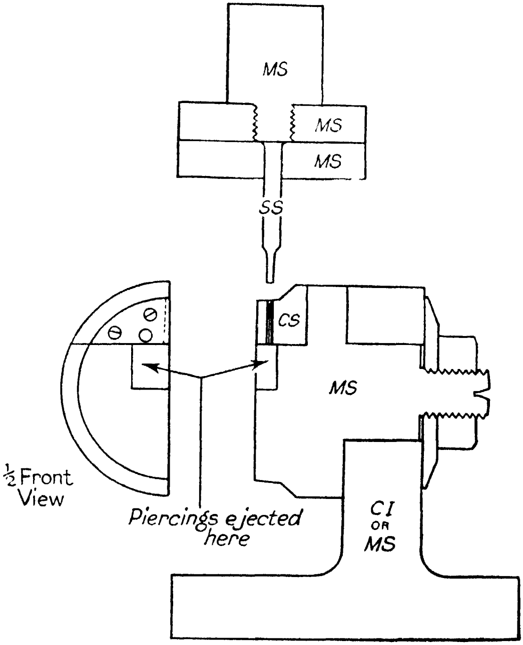


FIG. 40. PIERCING SIDE OF FORMED FITTING

PART ASSEMBLY

Certain progress can be made as regards assembly by threading the two arms through the centre clip and

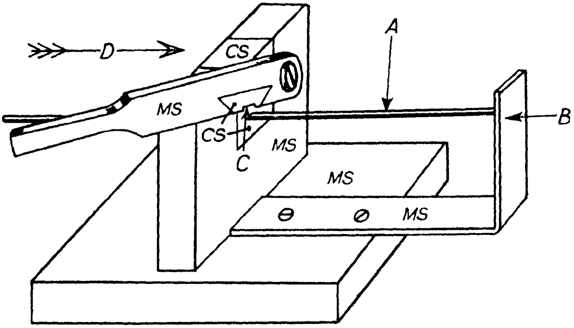


FIG. 41. SIMPLE HAND GUILLOTINE, USEFUL FOR CUTTING WIRE OR THIN STRIPS TO LENGTH

A.	Material to be cut
B.	Distance stop
C	Cutter
D.	Metal fed through in direction of arrow

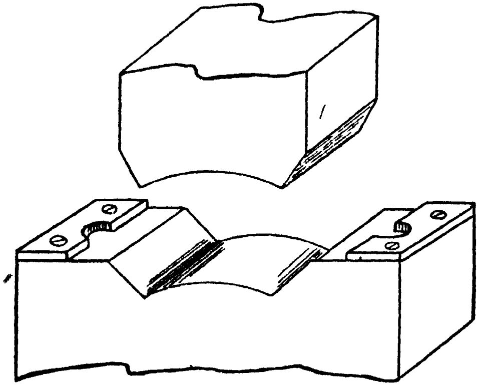


FIG. 42. SHOWING SOLID PUNCH AND DIE FOR BENDING TOOL

riveting the top arm to the shade support. This can be accomplished on a tool similar in design to that of Fig. 40, with a recess in the die, instead of a piercing hole, to accommodate the head of the rivet, and a snap punch instead of the piercing punch. This again is a light hand-press operation. At this stage, a tool will be needed to produce the set-off at the bottom of the support arm (see 3, Fig. 35), and will represent that shown at Fig. 43.

SPRING CLIP

The spring clip calls for two blank and piercing and two bending tools, all of which are of usual design. The two halves of the clip differ, in that one has slotted piercings to fit the arm, and the other round piercings, details of which in their blank form are shown in Fig. 44, and in section when assembled at Fig. 44A, so it will be seen that much care is needed in determining their individual blank sizes and piercing centres. No descriptive reference is needed regarding the blanking and piercing tools, but the bending is somewhat more complicated than those already dealt with in the preceding pages. Two separate bending tools are needed, similar in design and construction, but of different proportions to produce the varied width to which the lugs are bent. Tools with spring pads will be used for these, but, unlike the one described in Fig. 8, the pads and punches are formed to the finished shape. Again, provision must be made for bending the lugs, by means of side pieces inserted, a plan of which describing these details is shown in Fig. 45. The making of the spring that is used to cause the gripping action hardly comes within the scope of this section, and it is always advisable to purchase this from a firm that specializes in this class of production. Now that all the various units have been completed, they can be

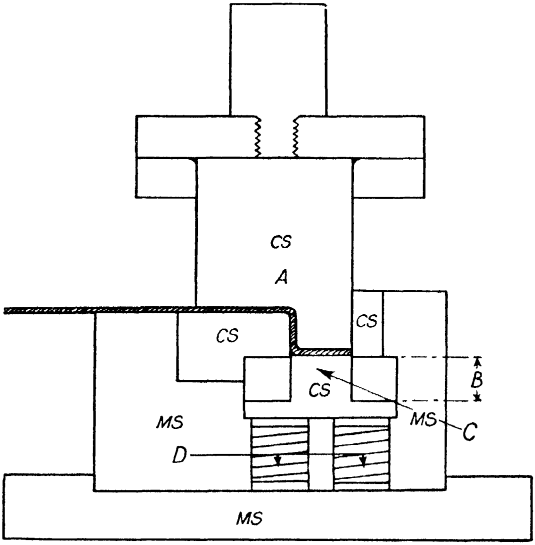


Fig. 43. Bending Tool showing Bends Completed

Shaded portion represents the fitting
Sectional view showing main working principles

A. Punch
B. Travel of pad
C. Pad
D. Springs compressed

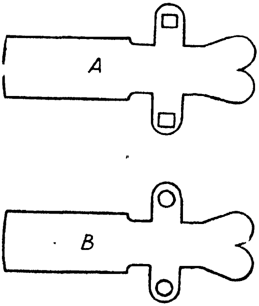


Fig. 44 Showing the Difference in the Two Blanks of the Spring Clip

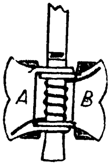


Fig. 44a. Assembly of Spring Clip

assembled, and the lower end of the support arm distorted in such a way as to prevent the components falling adrift. This may be accomplished either by gripping in the vice or by flattening in the press between a flat punch and die.

THE PRODUCTION OF A TOY TRAIN WHEEL

Introducing Combination Tools, embodying Blanking, Piercing, Forming, and Embossing in One Operation.

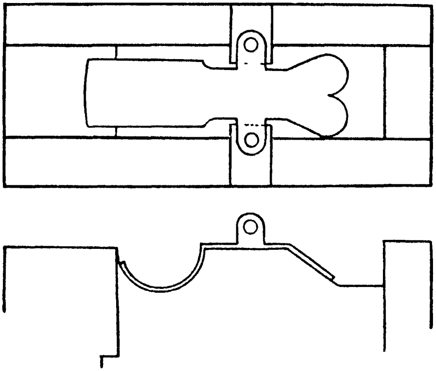


FIG. 45. PLAN AND SECTION OF BENDING DIE

In explaining the method by which it is possible to produce toy wheels, only one of the many thousands of units needed in the toy industry will be dealt with. In this particular branch, foreign competition is normally very great, especially so as regards price cutting.

There is, however, a tremendous scope and demand for British toys, and it is only the employment of well made and carefully planned tools that will satisfy this demand in price and quality. It is usual practice to have sheets of tin printed with the required

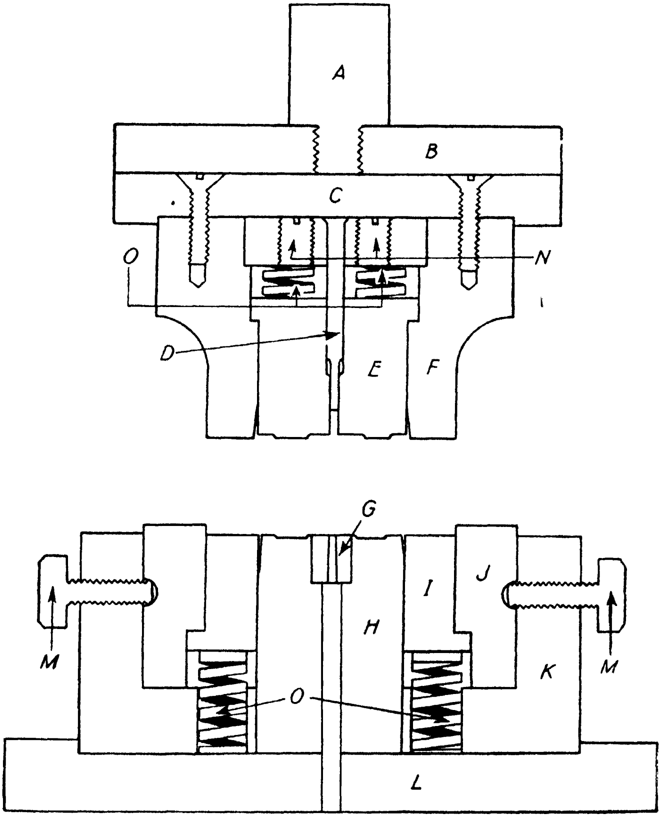


FIG. 46. SECTIONAL VIEW OF COMBINATION TOOL

A.	Spigot	*F*.	Blanking punch	*K*.	Die housing
B.	Spigot plate	*G*.	Piercing bush	*L*.	Base plate
C.	Punch plate	*H*.	Embossing die	*M*.	Fixing screws
D.	Piercing punch	*I*.	Spring pad	*N*.	Adjusting screws
E.	Embossing punch	*J*.	Blanking die	*O*.	Springs

design, therefore it is necessary to make accommodation for registering off the edge of the sheet until it is possible to obtain the position from the scrap. The actual planning of this can only be decided to suit the individual blank, the travel of which is again determined by the lay-out of the printed sheet. The wheel on which we are about to concentrate (see Fig. 46A) is made up of two blankings, assembled in the press, and will require one combination, one blank and piercing, one forming and one assembly tool for its entire production. Fig. 46 shows in detailed section the actual working principles of the combination tool for producing the front portion of the wheel (see *A*, Fig. 46A). This tool is somewhat of a departure from those previously described; it is necessary to dwell upon this in detail. It must be borne in mind that the blank size must be determined before any work of a definite nature, regarding the punch and die, can be entertained, therefore it is essential that the drawing portion should be

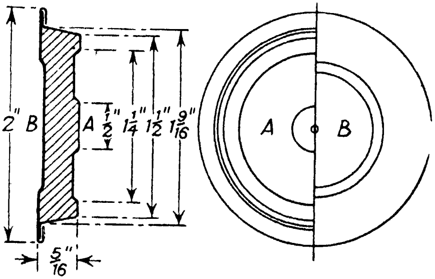


FIG. 46A. DETAILS OF TOY TRAIN WHEEL

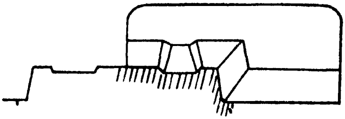


FIG. 46B. DETAILS OF HALF PROFILE GAUGE

the first unit to receive attention. The diameter of the wheel is the unit by which the size of the tool is decided, and, to arrive at this, it is advisable to sketch the main construction, allowing the necessary practical sizes for the blanking die and its housing. To make this clearer, the wheel in question is of 2 in. diameter when finished. The blank size will be approximately $2\frac{3}{4}$ in. diameter. Allowing at least $\frac{5}{8}$ in. all round for the die, brings it up to $2\frac{3}{4}$ in. $+$ $1\frac{1}{4}$ in. $=$ 4 in. Again, the wall of the housing will need to be at least $\frac{1}{2}$ in., which gives the outside diameter as 5 in. The base plate will therefore have to be large enough to accommodate a 5 in. recess, plus sufficient metal to form a flange for holding down purposes. Having satisfied oneself on these general proportions, the base plate *L*, Fig. 46, can be prepared, with the recesses turned to register the mild steel die housing, and the centre embossing die. This must be made of $\frac{5}{8}$ in. mild steel plate, in order to withstand the direct blow of the embossing punch.

EMBOSSING DIE

Two and a quarter inches should prove a practical height from the base plate to the working face of the die, therefore a piece of cast steel $2\frac{3}{8}$ in. × $1\frac{5}{8}$ in. diameter should be cut off, from which the embossing die will be formed (see *H*, Fig. 46), using a carrier with front and back centres, turned down to $1\frac{1}{2}$ in. minus the double thickness of metal. Make absolutely sure the turning is parallel and to size, by checking at various points with the vernier, or 2 in. micrometer. Remove the centres, and fit an independent four-jaw chuck. With the end that was held by the carrier, facing the tailstock, insert the embossing die in the chuck, screwing down the jaws lightly so as not to mark the finished surface. To prevent damage, unscrew one jaw and place a piece of soft brass between the jaw and the die, and again screw down lightly. Repeat this on the remaining jaws, and then the process of truing-up may be taken in hand. Fix the tailstock and back centre, and with the aid of a test indicator, fixed to the arm of the scribing block, adjust each jaw until correct reading results. Making sure that the jaws are all now screwed up tight, and no movement is likely to occur, remove the tailstock to the further end of the lathe bed, there being no other use for this for the time being. Face up the die until the required length is obtained, namely, 2¼ in. plus the depth of the recess in the base plate. With the help of a half profile gauge (see Fig. 46B), carefully turn the form, which must when finished present a polished surface free from all machine marks. Any irregularities occurring here, if not rectified, will be reproduced in the product. A centre hole needs drilling through which the piercings have to pass, therefore a ¼ in. hole is decided on, for two reasons, namely, to ensure against the possibility of the piercings binding up, also to afford accommodation for the removal of the centre piercing bush (see *G*, Fig. 46). Here again the tailstock will be needed for holding the drill chuck. To guarantee drilling central, use a centre bit, or a ¼ in. drill, with its working end supported by a tool or square bar held in the tool post, until the correct centre is obtained. Having drilled right through, remove the tailstock, and with a small boring tool fixed in the tool holder, commence to bore a flat-bottomed hole, large and deep enough to accommodate the piercing bush.

THE PIERCING BUSH

Perhaps the query arises as to the actual use of a bush being inserted in a cast steel die. It has its twofold uses and advantages, which are as follows: Assuming, in the absence of a bush, the edge of the piercing hole was chipped or became blunt after much use, the fact of having to grind over the face of the die at once alters the contour of the form, whereas with a bush it may be packed up or replaced. Again, a bush ½ in. long is much easier to back-off with a "D" bit, or taper reamer, than the punch 2¼ in. in length would be. This will take the form of a piece of cast steel turned to fit tightly in the counterbore with a $\frac{1}{16}$ in. hole, back off.

DIE HOUSING

The next unit to receive attention will be the die housing, for which a piece of mild steel 2½ in. × 5½ in. diameter is required. This must be held (see *K*, Fig. 46) in an independent four-jaw chuck, and turned to fit the recess in the base plate, continuing the same diameter for at least 2 in. Whilst in this position, bore a centre hole to suit the diameter of the embossing die, namely, 1½ in. Also face up to form the base. Reverse this in the chuck, using as before the brass packing pieces. Check the bore and outside diameter with the indicator, and when correct reading is recorded, turning and facing may be continued until the housing measures 2¼ in. plus the depth of recess. Further boring may be done to within ½ in. of the outside and 1½ in. deep, leaving a true flat bottom on which the die has to rest.

SPRING PAD

I, Fig. 46. The exact outside diameter of this cannot be decided until some bit of experimenting with the blank sizes has been done, but as it is needed for these experiments, some size larger than required must be employed; therefore, to be on the safe side, a ring to form this pad will be turned ⅝ in. in width.

Cut off a piece of mild steel 1¼ in. × 3 in. diameter, and in a four-jaw chuck bore out the centre to allow the embossing die to pass through as a sliding fit. Face up the end and turn the outside diameter to 2¾ in. approximately. Reverse in the chuck as before, and continue turning and facing until it measures 1 $\frac{3}{16}$ in. in length. This is all that can be done to this unit for the time being.

A series of holes may be drilled in the die housing for springs, in such a position as to operate on the base of the spring pad. It will be seen that we now have the bottom portion complete minus the die.

So much, then, with regard to the die housing and spring pad. Attention will now be directed to the embossing punch.

THE EMBOSSING PUNCH

Passing to the top portion, the embossing punch is the first unit to put in hand (see *E*, Fig. 46). This is so designed that, on the point of the press reaching the bottom of the stroke, it forms solid contact with the punch plate, and has precisely the same amount of movement as the spring pad. In case adjustment is needed here, a number of hardened screws are introduced (see *N*, Fig. 46), by which means it is possible to regulate the amount of travel. The same method may be adopted for the spring pad, but it is advisable to have one or the other positive, the reason being that in the event of re-assembly, no difficulty is encountered in reproducing the preceding product. A piece of cast steel 1½ in. long × 2 in. diameter is needed for this punch, which is mounted on front and back centres, and turned to 1½ in. plus double thickness of metal, parallel to within $\frac{7}{16}$ in. of the back face. To prepare for turning the formed end, special brass packing pieces must be made, or a brass ring turned and split, thick enough to stand above the ledge, so that it is possible to grip the punch by its finished surface in the chuck. The form needs to be a replica of the die plus a thickness of metal. For roughing out, another profile gauge will be required, but an absolute fit can only be obtained by bedding the two units together. Secure a piece of soft brass sheet of the desired gauge, and, with the aid of the die and a hide mallet, attempt to reproduce the form by light tappings. Care must be taken here not to apply sufficient force to move the punch from its original setting. The high and irregular places will be easily detected, and should be adjusted with scrapers until the two surfaces are faithfully reproduced. Before removing from the chuck, drill the piercing punch hole (see *D*, Fig. 46), with a $\frac{1}{16}$ in. drill $\frac{1}{2}$ in. deep. Do not attempt to drill this right through, as such a small drill is liable to run out in such a length. The punch can now be reversed, and the back turned and faced up until it measures $1\frac{7}{16}$ in. in length. At this setting, drill a $\frac{3}{16}$ in. hole central until it meets the smaller one. This is to accommodate the shank of the piercing punch.

SPRING AND PUNCH HOUSING

See Fig. 46. A mild steel disc, $\frac{1}{2}$ in. × $2\frac{1}{2}$ in. diameter, will have to be turned to accommodate the springs, punch, and adjusting screws. These must all be spaced out to the best advantage. No allowance need be made for fixing, as the extra diameter allows for it to be housed in the back of the blanking punch, which is eventually registered, screwed, and dowelled to the punch plate. A $\frac{3}{16}$ in. reamered hole must be made in the centre, countersunk at the back, into which the piercing punch is fitted. It is advisable to make provision for screws of a large diameter and fine pitch, so as to obtain the fine adjustment that may be necessary.

THE BLANKING PUNCH

F, Fig. 46. Like the spring pad, only a certain amount can be done to the blanking punch, but this certain amount is essential to carry out the necessary experiments. Cut off a piece of cast steel, 2⅜ in. × 3½ in. diameter, and set up in the four-jaw chuck. Bore out the centre to admit the embossing punch as a sliding fit. Face up the end and turn the outside diameter to 3 in. Whilst in this position, a slight form will have to be turned to allow it to pass over the tapered end of the embossing die. Making further use of the brass form, bed the punch and die together in the same manner as before, until the desired fit is obtained. Reverse the punch and face up the back end, until it measures 2¼ in. in length, and bore out the extra diameter to admit the spring, screw, and punch housing as a tight fit. Clean up the outside to form a true radius.

PUNCH AND SPIGOT PLATES

A, *B*, and *C*, Fig. 46. As the largest diameter of the blanking punch measures approximately 3½ in., and has to be registered in the punch plate, the size of this will be arrived at as 3½ in. plus 1 in. = 4½ in. diameter × ⅝ in., and 4½ in. × ½ in. for the spigot plate. These are assembled in the usual way with cheese-headed screws and dowel pins.

FINAL ASSEMBLY

It will be seen now that every unit has been taken in hand excepting the blanking die, which must still be left for the time being. All components may be assembled in their soft state, employing the use of temporary springs for the spring pad, strong enough to support the pad to the height of the working face of the embossing die. In place of the piercing bush, insert a plug with a $\frac{1}{16}$ in. pin standing above the die, to act as a temporary register for the experimental blanks. Cut off several blanks of the right gauge metal (soft brass in preference, so as not to damage the tool), varying in size about $\frac{1}{32}$ in. Fix the tool in a press, and try out these blanks until the right size has been determined. As this is almost an impossible decision to arrive at by theory, in any case a very unsatisfactory one, we must assume that after these experiments the size arrived at is $2\frac{1}{4}$ in. diameter. To make doubly sure, cut and try out another of the same size, it being better to take this precaution now, rather than wait for the actual production; $2\frac{1}{4}$ in. is again proved right, so the die can now be commenced (see *J*, Fig. 46).

The boring of the die housing determines the outside diameter, which is approximately 4 in., and the blank size the inside bore. Measure the depth of the bore in the die housing plus $\frac{1}{4}$ in., and cut off a piece of cast steel that will machine up to conform with the desired sizes. The die has to stand up above the face of the embossing die in order that the blanking may be done first; $\frac{1}{16}$ in. may be allowed for this. Mount the steel in the chuck and bore out the centre, $2\frac{1}{4}$ in. diameter less 0·005 for grinding. Assuming this to be the base of the die, bore out still further to accommodate the flange of the spring pad, allowing $\frac{5}{16}$ in. movement. As this flange is not yet in its finished stage it must be determined as $\frac{1}{4}$ in., therefore the bore will be $\frac{5}{16}$ in. plus $\frac{1}{4}$ in. deep. Turn the outside diameter to suit the bore of the die housing plus 0·005 in. for grinding. Reverse in the chuck and finish turning the outside, then face up until it is in length equivalent to the depth of the bore plus $\frac{3}{32}$ in. This will allow for grinding the top and bottom faces. Before removing from the lathe, turn a half round shallow groove for fixing in the housing by means of a series of screws (see *M*, Fig. 46).

The die may now be hardened and tempered, and ground to size. The inside bore needs checking with an inside micrometer or vernier, and the outside to be a comfortable fit in the housing. When this is completed the spring pad needs turning to suit, and should form a sliding fit with its two components, the embossing and blanking dies. Remove the temporary plug from the embossing die, and the die from the base plate for hardening and tempering, afterwards polishing up the working surfaces with a fine carborundum stone. Harden and temper the piercing bush, insert in its position and stone off level. The whole bottom portion can be permanently assembled, by screws and dowel pins of practical sizes.

As the micrometer size of the bore of the blanking die has been determined, the blanking punch can be set up and turned to suit plus 0·005 for grinding. This diameter may be blended into the larger size of the back end, from a distance of about 1 in. from the face. Remove from the chuck for hardening, tempering, and grinding, checking for size with the vernier. The centre piercing punch needs turning from $\frac{3}{16}$ in. silver steel, and in length must be about $\frac{1}{4}$ in. less than the depth of the embossing punch. By this means the piercing punch does not come into action until displacement of metal, that would occur at this point, is completed, or nearly so.

After hardening and tempering and fixing in its respective housing, the whole may be finally assembled and tried out. The action that takes place is as follows. The blanking punch is the first to enter the die, so cutting the blank. Next, the embossing punch under the pressure of the springs partly forms the metal, at the same time the blanking punch, on its downward path, is carrying the edges of the blank between it and the spring pad, forming the rim of the wheel. A little further, and the piercing punch does its work, and at the bottom of the stroke all should be solid with the metal completely formed. On the upward stroke the spring pad forces the formed blank back again to its original position to be removed by the operator. An inspection of the product will prove what has actually taken place, and if any adjustment is needed. This can be done by lowering the ram, or adjusting the amount of travel in the punch portion by the screws fitted for that purpose.

BACK PORTION

The actual reasons why an ordinary blank and piercing tool should be recommended for a fitting, such as shown at *B*, Fig. 46A, may at first sight appear rather baffling. One may say that the fitting already completed, by one blow of the press, has treble the amount of operations, and rightly so, but allowing a little time for thought, it will be seen how unpractical it is to attempt the production of this in the same type of tool as that already explained. Referring back to *A*, Fig. 46A, it will be seen that the amount of metal from the edge of the form to the outside blank size is approximately $\frac{3}{8}$ in. all round, and it is this that gives body and strength to the blanking punch, but in *B* there is only $\frac{1}{16}$ in. to be turned up, which would leave the walls of the blanking punch $\frac{1}{16}$ in. thick, the centre having to be bored away to accommodate the forming punch.

FORMING TOOL

Again, in this case the forming tool will have to be made first before the blank size can be determined. This can be of quite simple design, and will take the form of construction as shown in Fig. 47. A somewhat different type has been introduced here, to illustrate how in some cases it is impossible to accommodate springs in the die housing or bolster. Pressure is transmitted by pins passing through the base plate on a

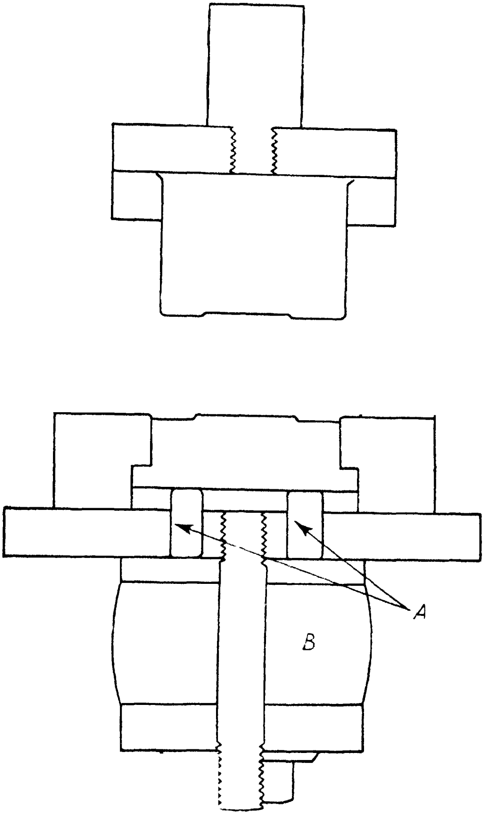


FIG. 47. SECTION OF FORMING TOOL
A. Pressure pins
B. Rubber

rubber pad, or springs, which are housed underneath. As will be seen by Fig. 46A, the outside diameter of the wheel is 2 in., therefore the die will have to be bored to suit with a slight radius on the drawing edge, and form the back recessed to accommodate the flange of the spring pad. The register plate will have to be bored and fitted after the blank size has been decided. Turn the pad to a nice sliding fit in the bore of the die, and on its face turn the form. The diameter of the punch will be 2 in. less double the thickness of metal, with its working face turned to suit the form of the pad plus the thickness of metal. These two components will need bedding down to each other, in the same way as explained in the previous combination tool. The punch and spigot plates will have to be large enough to accommodate the fixing for a spring stripper, the use of which is necessary to extract the drawn blank from the punch. This will have to be a good fit, as there is only thickness of metal to press against. A small temporary pin can be fitted to the centre of the pad for registering the blanks, to be dispensed with when the right size is obtained. When the necessary holding down and register plate holes are drilled and tapped, and the guide holes drilled and reamered to size, the punch, die, and pad can be hardened and ground, and assembled, to try out the experimental blanks, on decision of which the register plate can be bored and fitted. For the blank, an ordinary follow-on blank and piercing tool could be designed, but owing to the light gauge of metal, a much better product results from one designed on the lines of that described and recommended for light work, namely, the blanking tool with spring stripper (see Fig. 20).

ASSEMBLY TOOL

Having at this stage the finished front and back form which comprises the wheel, a tool is necessary for assembling them. This tool, as shown at Fig. 48, may appear very simple indeed, but care in making must not be neglected in any way, if good production is required. It is just that little that will make or mar the effect. Quite a time may have to be spent before

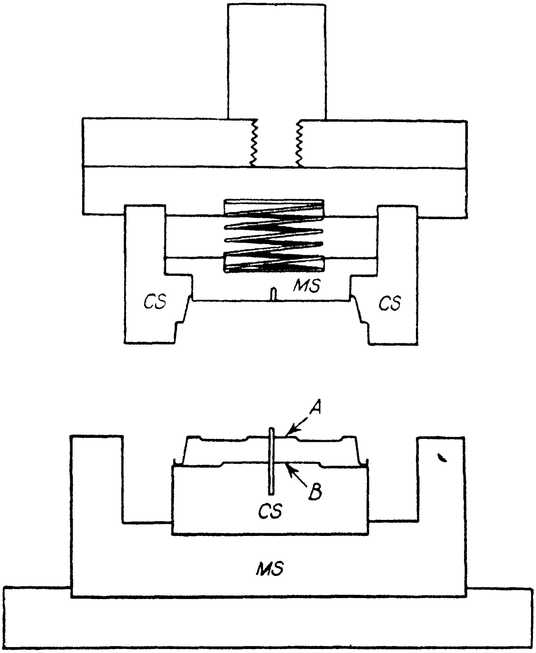


FIG. 48. SECTION OF FINAL ASSEMBLY TOOL
With wheel blanks *A* and *B* in position

the required angle or radius can be obtained on the punch, and until that form can be obtained, perfect production will not be forthcoming. A pad, very lightly sprung, is fitted in the punch to overcome any binding that may occur. The strength of these springs must be so adjusted as not to distort the wheel, but at the same time they must be strong enough to carry out their work of extraction.

BRIEF DESCRIPTION OF LARGE TOOLS

It is now opportune to explain that the candle shade holder and toy train wheel were chosen for description, just as fictitious characters are chosen for a novel, and that the descriptions do not apply only to these, but the principles embody ways and means of producing articles of a similar nature too numerous to mention. Not by any means are these small articles the limit of the press, tools sometimes reaching such proportions that it is necessary to employ the use of tackle to move them from place to place. A glance at the wings, running boards, radiator frames, corner panels, and other large units of the motor industry, domestic tin and enamel ware, trunks, large advertisement plates, etc., will convey to the uninitiated an idea of how great in size the tools needed to produce these must be, and we will endeavour to explain briefly the principles employed and tools needed for this larger kind of product.

DOMESTIC BOWLS AND BASINS

Blanking tools for these can be turned out of the solid, or built up according to their size. The blanks are then rough, and are finally formed in cast top and bottom tools, which have been carefully fitted to each other. Rough edges and superfluous metal are cropped off ready to be beaded, after which handles, spouts, and other fittings are press assembled.

STOVE CANOPIES

Embossed metal as used for fire canopies, screens, curbs, panels, etc., is usually the product of cast tools. In the first instance, a wooden male and female pattern is made, ready for the moulders. After the castings are received, much time and care are spent in filing, scraping, and chipping to make these a perfect fit. Should a faulty casting result or a blow-hole appear, it is usual practice to drill out the affected parts and insert mild steel plugs, on which the pattern is again reproduced.

EMBOSSED METAL ADVERTISEMENTS

In casting for a name sign, the die is negative and the punch positive. These can either be cast solid, or the name and design, or whatever is required, may be fitted to a cast punch taking the general form. Beading can be accomplished by the same method, and so on in countless instances.

SECTION XXII

PRACTICAL BLACKSMITHING

BY
W. EMERSON, M.I.W.E.

SECTION XXII

PRACTICAL BLACKSMITHING

IMPORTANCE OF THE BLACKSMITH

THE blacksmith's trade is the foundation of crafts, it is an ancient, honourable calling. No doubt he is practising the oldest craft known to us to-day, and iron, the material he works, has properties of which he has to take full advantage. When heated to red it is exceedingly malleable and ductile, and can be formed into any shape he desires. He can make a homogeneous joint by bringing the iron to a white heat and then welding it--in fact, we can say that iron contains the working qualities of all the other metals. Thus the smith finds little difficulty working any metal, and he is often known by the metal he specializes in.

No wonder the blacksmith, making wonderful things with iron, was held in such high esteem during the Middle Ages. No progress could be made without his aid, weapons for protection, shoeing of horses, making agricultural implements, tools for the masons and carpenters, etc. Yes, even the cook needed him for the kitchen utensils. All these needs kept him constantly employed, and so important was he that in Anglo-Saxon times a double penalty was inflicted on anyone who assaulted him. He held high rank in the King's Court, being placed immediately after the Court Chaplain. From those early times to the present his inventive skill has been the means to which we owe our present state of progress. To working blacksmiths must be given some credit for the " steam engine, iron ships and bridges." The poet Longfellow wrote true words when he said: " The Smith, a Mighty Man is he." Not only muscle and brawn are required to make a smith, but brain also.

There is no end to the number of jobs the blacksmith is called upon to undertake ; there is not a trade but requires his assistance in some way or other. The term Blacksmith is therefore a very wide one. Many of its branches have become specialized, but the elements of blacksmithing are the same in all branches. The small general smithy, where a great variety of work is undertaken, is perhaps the most fruitful source of young blacksmiths emigrating to the large industrial centres, where they become specialists in some branch or other.

The object of this section is to give to the young blacksmith some of the elementary principles which are common to all branches of the trade, and to show a few examples of the more specialized branches.

It is for the young blacksmith to acquire the habit of thinking how he would do a given job, and to compare his ideas with the methods adopted by his older brethren ; he will often find they have different ways of starting a job, but the completed job will be the same.

Thus he will train his reasoning powers. and be able to solve more easily problems that will come to him in later life.

He must obtain a knowledge of drawing and understand plans, elevations, and sections if he is thoroughly to visualize the completed article he will be asked to make ; without this knowledge he will be unable to plan how he is to proceed with the job.

THE SMITHY

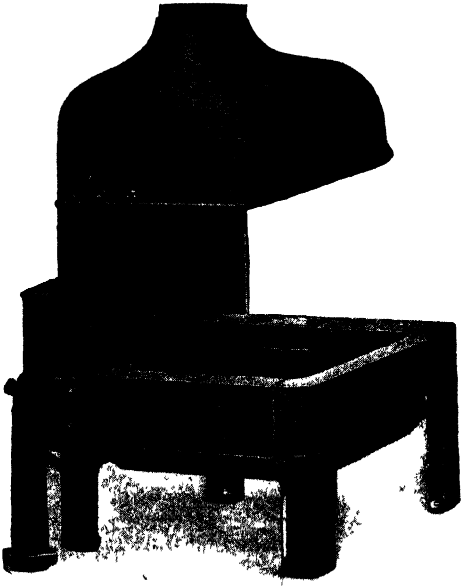
The smithy of the past was often found in some dark, dismal, out-of-the-way place, having low ceilings and few windows, its light being obtained from the glare of the fire or from the door immortalized by the poet Longfellow; any glass that may have been in the roof or windows was obscured by dirt or grime. Such shops were not roomy, and were often made less so by an accumulation of oddments. Unfortunately, we still find such conditions in small shops, especially in our cities, where rents are so high. The wonder is the blacksmith working under such conditions produces the work he does.

How different are the smithies being built to-day by our large engineering firms! They are very lofty, and generally the roof is mostly composed of glass. The shops are arranged to suit the work to be produced in them, the hearths are arranged along the sides. The heavy smithy has suitable steam and power hammers and other appliances for the work to be done. Overhead there is a travelling crane, and runways are provided to place the material or work where it is required without any disturbance or fuss. The blacksmiths in these large forges are usually specialists.

In the smaller smithy, work of a more general character is undertaken. There is not much difference in the general arrangement of the shop, but the mechanical aids are of a lighter construction, and where the work is mainly hand forging these mechanical aids are only used where great reduction of material is necessary. Otherwise the work of hand forging is very little changed from what it has always been, excepting that iron in which the grain of the metal has to be constantly considered is now almost entirely supplanted by steel, the regulation of heat being the more important factor of this material.

BLACKSMITH'S APPLIANCES

The Forge. The forge or hearth in which a blacksmith heats his iron is made up in various forms. Some years ago they were often made of brick standing out from the wall, as can still be seen in many of our village smithies. They take up a lot of room and collect a lot of dust where the bricks forming the hood to the chimney are stepped over one another.



(*Alldays & Onions*)

FIG. 1. "CLIMAX" FORGE

The iron hearth, as shown in Fig. 1, has to-day superseded the brick one; it is more elegant in appearance and is made adaptable to suit a number of requirements; not only single, but double hearths are to be had, with hoods, without hoods, or with hinged hoods. They are made either in cast iron or mild steel. Single hearths can be had in sizes varying from 2 ft. 6 in. to 5 ft. square. Another advantage of these iron

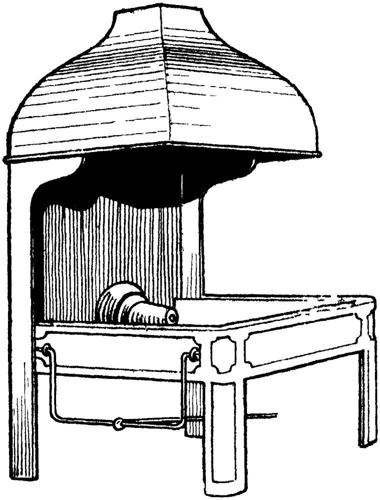
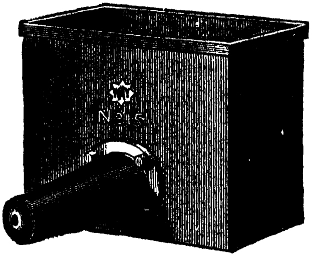


FIG. 2. HEARTH WITH FOLDING REST

hearths is that they are provided with gap plates in line with the nose of the tuyère, which can slide in and out at will and facilitates dealing with long bars.

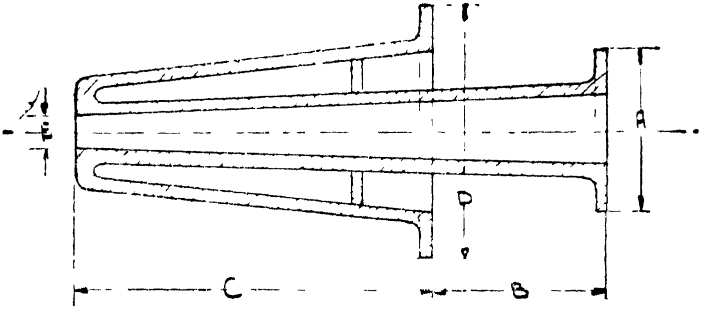
Although not provided by the makers, a useful addition to the hearth is a folding rest for supporting long bars while the ends are being heated (see Fig. 2). This is made of $\frac{3}{4}$ in. round mild steel, and shaped to fit the hearth and secured by eyebolts. It is supported by a leg in the centre, the perpendicular height being made to suit the ideas of the blacksmith. When not in use this leg can be pushed under the hearth, and thus the whole folds down out of the way.

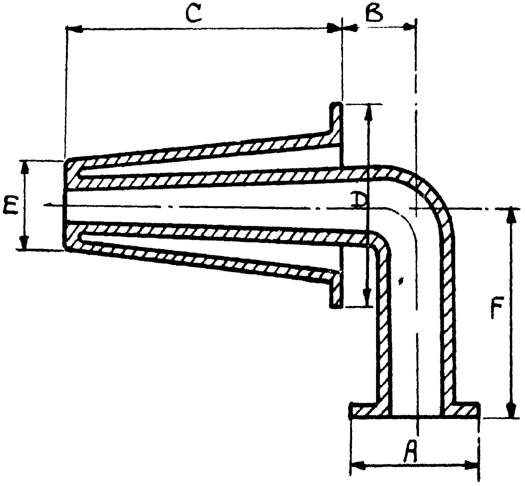


(*Alldays & Onions*)

FIG. 3. WATER BOSH

At the back of the hearth is a water bosh (Fig. 3) to which is attached a tuyère, very often called the tue-iron; the construction of this is shown in section (Fig. 4). It will be seen that the water in the bosh passes to and around the nose of the tue-iron, and thus keeps it cool when exposed to the heat of the fire. The





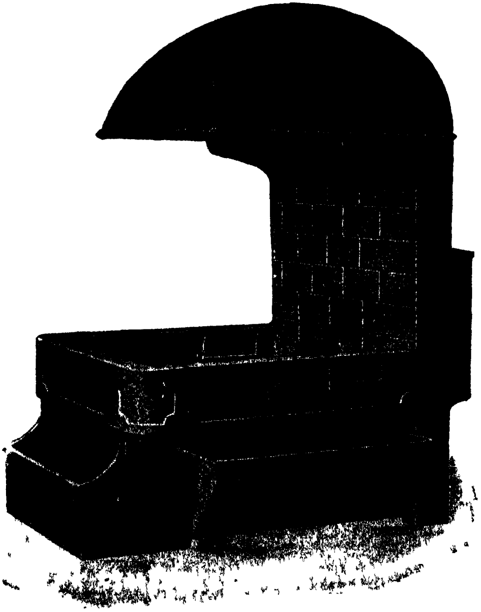
(Alldays & Onions)

FIGS. 4 AND 5. TUE-IRON SECTIONS

Above : Tue-iron for back blast
Below Tue-iron for side blast

centre passage allows the blast to pass from the back of the bosh to the fire. If, however, the blast is required to pass from either side of the bosh, a tue-iron as shown in Fig. 5 is available

At the front of the hearth there should be provided a deep trough, or bosh, for water, which is necessary not only for cooling the tongs, but also for cooling heated iron within limits for making short bends, upsetting, etc.



(Alldays & Onions)

FIG. 6. CHIMNEYLESS HEARTH

Where a series of hearths are required the latest development is known as the chimneyless hearth, an illustration of which is shown in Fig. 6, and a section illustrating its operation in Fig. 7. It will be seen that at the back of the hearth there is a cavity reaching from the hood to a smoke flue in the floor, the smoke or fumes being carried along this flue to an extracting fan or chimney stack. The main blast pipe is also sunk in the floor, and a branch taken from this to serve each fire.

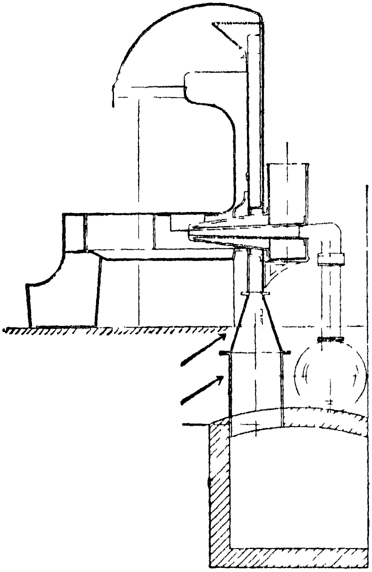


FIG. 7. SECTION OF CHIMNEYLESS HEARTH

The benefits of this hearth are its cleanliness, greater head-room, and the doing away with unsightly stack pipes passing through the roof, or the necessary pipes carrying the fumes to a common outlet.

The Blast. The method of supplying the means of combustion, air, i.e. oxygen, to the fire at pressure is by bellows, fans. or blowers.

Bellows of crude form have been used from time immemorial, but the old pear-shaped bellows are still in use and may often be seen in our village smithies; there is also the double blast, circular bellows, which are self-contained and take up less room. They give a more continuous blast, both the up and down strokes of the handle being effective.

Probably the most common means in use to-day is

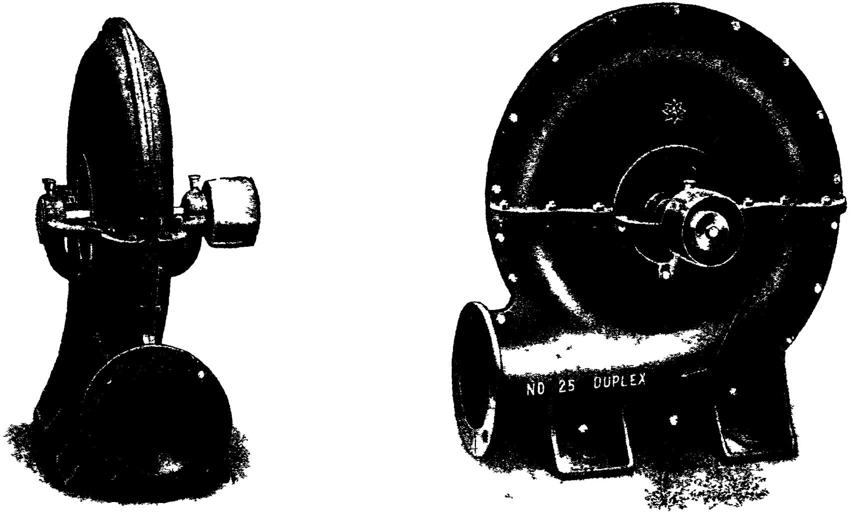


FIG 8. TWO VIEWS OF DUPLEX BLOWING FAN (*Alldays & Onions*)

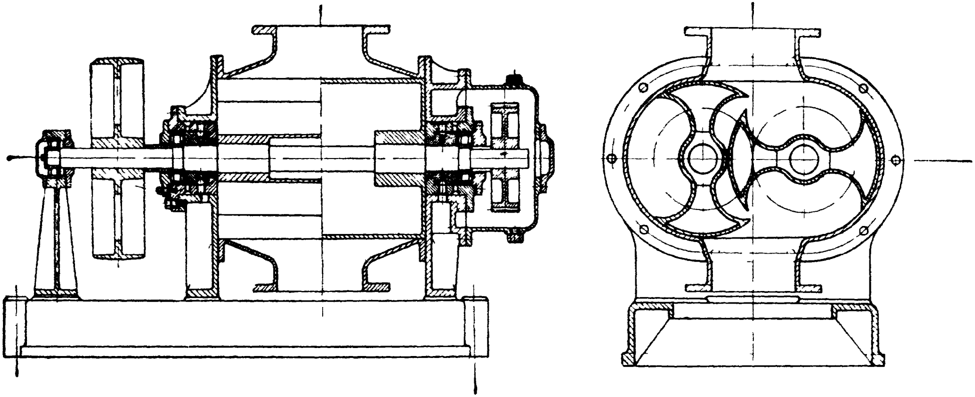
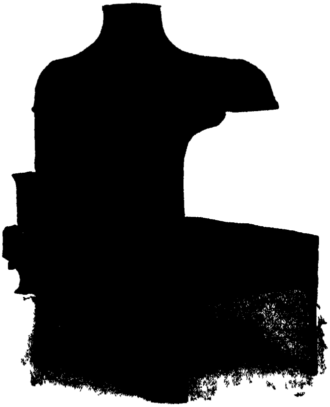


Fig. 9. Thwaites High pressure Positive Blower

the blowing fan (see Fig. 8), which is made to revolve from the shafting at a high speed by a belt. These fans are run on ball bearings. and are so constructed that they draw in air at the centre and deliver it as a strong draught at the outlet.

If a constant pressure of air is desired, the best machine for this purpose is a Roots type blower. Air is taken in at the top through a screened aperture and collected by two balanced revolvers of special shape, and forced through the main pipe at positive pressure. Fig. 9 shows the arrangement of this apparatus in section.

These blowers are not run at so high a speed as a fan; they are driven by pulleys from the shafting, the small ones having one pulley while the larger sizes require two pulleys, or, again, they may be prepared for coupling to an electric motor.



(*Alldays & Onions*)

FIG. 10. "MOTA" FORGE FAN

The volume of air from both fans and blowers is controlled at the fire by either a slide valve inserted in the delivery pipe, or a cock which is generally made at the top of a standard which bolts on the main delivery pipe in the floor.

Another of the latest developments is the fan with an electric motor attached, all in one complete unit and fixed at the back or side of the bosh behind the hearth as shown in Fig. 10, the controlling switch being fixed on the front of the hearth or in any other convenient position.

A poker, rake, and shovel will complete the equipment of the hearth.

Fuel. The fuel generally in use to-day is known as smithy breeze. This is really coke broken into various sizes suitable for the different classes of work.

The best breeze the writer has used is made in Sheffield. It is burnt in special retorts and tempered for smithy use and washed, making it very free from dust and giving very little clinker in use.

How to Start and Light the Fire. In starting a new forge the well of the hearth should be filled to the top of the tue-iron with clean ashes free from clinkers. Scoop out a layer in the ashes to below the tue-iron; the hearth can then be filled with the fuel. To light the fire scoop away the fuel to the bottom of the tue-iron and add a few shavings (or paper will do), light these and place a few chips of wood on top ; as soon as these ignite open the blast very gently and add a small amount of fuel on top; as the fire glows increase the blast and add more fuel. Soon the fire should have a good glow.

An important feature in the construction of a blacksmith's fire is to have plenty of burning fuel between the blast outlet of the tue-iron and the metal to be heated. If the blast be allowed to strike the heating metal, a film of oxide or scale will form, and the iron will become unevenly heated and will continue thus until the fire has been made to glow around the tue-iron. This fault may also occur by having the blast gate too open for the size of the job in hand. One of the most important lessons the young blacksmith has to learn is to control the amount of blast required for the job, and to keep his fire clean and free from clinker. He will soon learn how necessary are these observations during welding operations.

BLACKSMITH'S TOOLS

The Anvil. The anvil can be considered the tool of most importance after the forge. This is made in several shapes, but perhaps the two in most common use are the single bick (Fig. 11), which has a soft table as shown at the base of the bick, and the double bick, one end of the anvil having a round bick as illustrated, while the other end has a tapering flat top and is known as the square bick. The short rounded portion at the right-hand face shown (Fig. 11) should be made on all anvils, its object being to keep the iron from being checked or cut in when bending right angles. Few makers provide this improvement, but it can be easily filed by the blacksmith when missing. Anvils are made in various weights ranging up to 5 cwt., 2½ to 3 cwt. being the size mostly in use. The weight of an anvil is to be found stamped on the front.

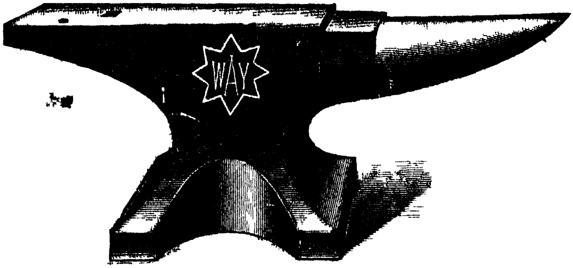


Fig. 11. Single Bick Anvil

Anvils are often fixed on a wood block fixed in the floor end grain up, and having an iron band fixed around the top to prevent the block from splitting, the anvil being held in position by iron pegs. These wood blocks are being superseded by cast iron stands (Fig. 12), which have the convenience of being able to be moved to suit any special job should it be required.

The Swage Block. The swage block is an essential tool to every anvil, its form being shown in Fig. 13. It is made in sizes from 11 to 24 in. square. The sides are indented with swage forms for round, Vee, and hexagonal shapes, the body having round, square, and rectangular holes for various sizes, all of which are useful for drifting, etc. When used on the flat it rests on a flanged recess on the stand, and if any of the sides is needed a vertical recess is provided, by which

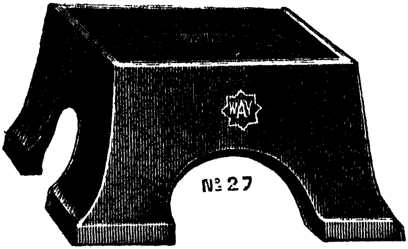


FIG. 12. CAST-IRON ANVIL STAND

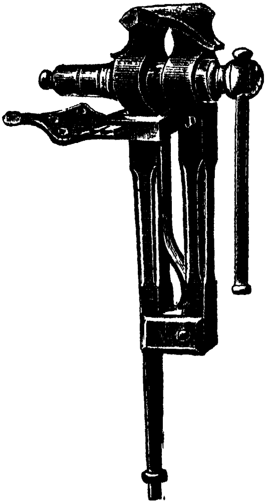


FIG. 14. HEAVY TYPE BLACKSMITH'S VICE

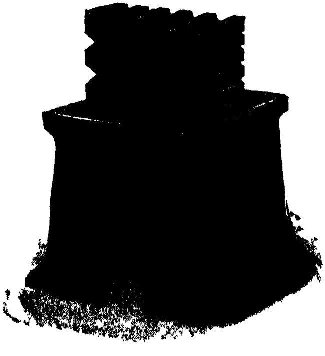


FIG. 13. SWAGE BLOCK

means the block is held firmly while in use as shown in the illustration.

Levelling Plate. This is useful to all blacksmiths and angle iron smiths, particularly for levelling curved work, and, if arranged with holes in series in which pegs can be inserted, heavy material can be bent to any shape and kept flat at the same time. It is to be had in sizes varying from 3 ft. × 2 ft. to 6 ft. × 4 ft., or larger if specially ordered.

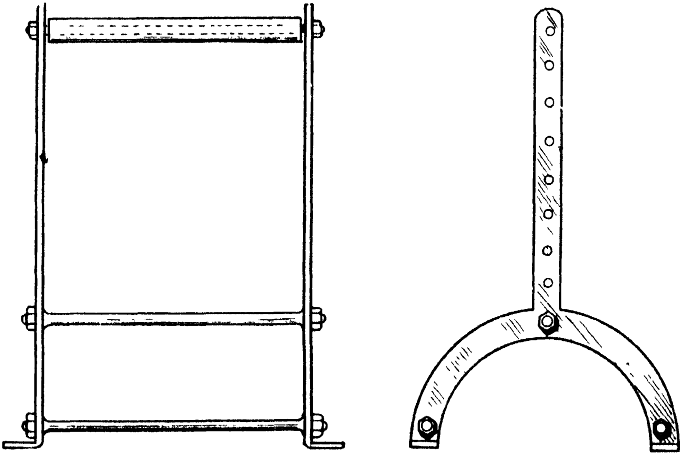


FIG. 15. ADJUSTABLE WORK STAND

Smith's Mandrel or Cone. These cones are used in truing-up rings. They are made in varying tapers from 1½ in. at top and 9 in. at bottom, to 9 in. at top and 20 in. at bottom. The heights vary from 3 ft. 3 in. to 5 ft. There is a groove from top to bottom to receive the nose of the tongs gripping the work.

Vice. A heavy vice with 6 in. jaws fixed near to the forge is a tool of great assistance to the blacksmith (see Fig. 14).

Work Rests. For very heavy forgings it is necessary to have an overhead runner with pulleys and provided with a sling chain over a pulley. This must have a screw for making vertical adjustments to suit the work to the anvil, and also a swivel by which the work is moved at any angle while manipulating from the fire and on the anvil.

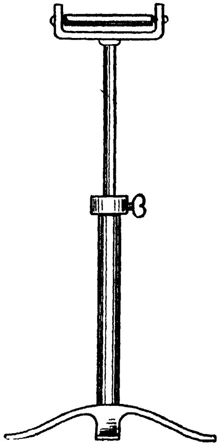


Fig. 16. Lighter Form of Adjustable Work Stand

For long bars, etc., work stands with a roller bar on top are needed. These are made by the blacksmith himself. Fig. 15 shows an adjustable one having two legs, kept apart by three tie bolts at the semi-circular bases. The fourth bolt which passes through a tube is adjustable by fitting through any of the holes shown in the upright stem.

A lighter form is made up of a tube with a collar secured at the top to which an adjusting screw is fitted, the bottom of this tube having a plug and collar welded on and a square tenon formed for riveting to the foot. A round bar which slides into the tube is now welded to the centre of a flat bar and the end turned up to take a short bolt and roller as before, the adjustment being obtained by a number of deep countersinks in the round bar into which the adjusting screw at the collar fits (see Fig. 16).

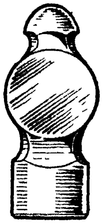


Fig. 17
Ball Pane

The Hammer. After the anvil the hammer is the tool of most importance to the blacksmith. Those used by him are the "hand hammer," the "sledge," and the "backing hammer."

The hand hammers usually served out to-day are really fitters' hammers which have a ball pane, as in Fig. 17. The face of these is very flat and should be ground to give a slight fullness in the centre, otherwise the edges cut in and mark the work.

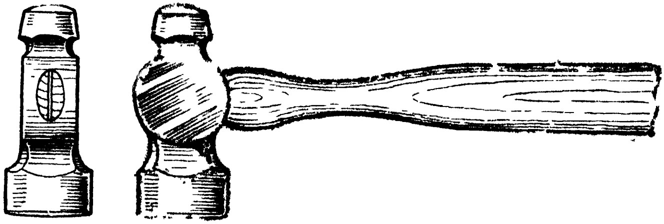


FIG. 18. BLACKSMITH'S HAND HAMMER

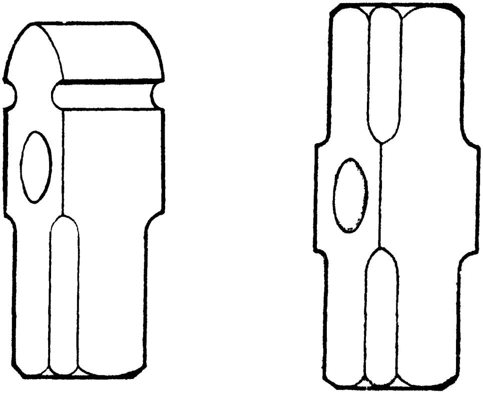


FIG. 19 FIG. 20

TYPICAL SLEDGE HAMMER HEADS

The true blacksmith's hand hammer is shown at Fig. 18, but such hammers are generally made by the smith himself. The method of making these will be described later.

The second hammer is the sledge which is used by the smith's helper or striker. Two forms of these are in common use; that shown in Fig. 19 has the pane in line with the shaft, while that in Fig. 20 shows the double-faced sledge. These hammers vary in weight from 7 lb. upwards.

The third hammer may be described as a heavy hand hammer weighing 4 to 5 lb., and is known as a backing hammer; it is used where the blacksmith requires a series of quick light blows on the work, and may also be used when thickening or upsetting the end of a bar.

The hammer is such a constant companion to the blacksmith that it really becomes a part of himself (it takes a long time for him to become used to a strange hammer). To add to his comfort a wood shaft having a degree of springing near the head should be provided, the handle portion being oval shaped to fit the hand. Such a shape will not jar and, consequently, better work will be produced.

Tongs. To handle his work while forging, the blacksmith requires suitable tongs to hold the work. A variety of these are required, and there are occasions when the blacksmith finds it necessary to devise special tongs to hold the work in hand. Certain forms are in constant use, some of which are illustrated in Figs. 21–32.

CLOSE TONGS (Fig. 21). These are used for holding thin stock.

OPEN MOUTH TONGS (Fig. 22). This type is suitable for holding heavier stock, and should have a fuller groove in the mouth which, apart from giving greater grip, assists in holding other forms of stock.

HOLLOW BITS (Fig. 23). These are used to hold round, hexagonal, or octagonal material.

CHISEL OR BOLT TONGS (Fig. 24). The head of the

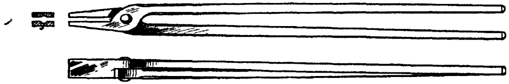


Fig. 21

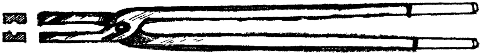


Fig. 22

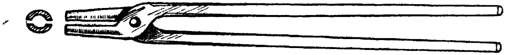


Fig. 23

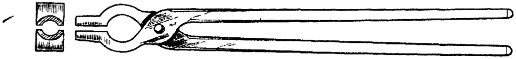


Fig. 24

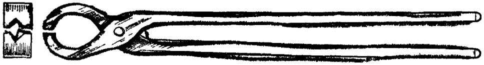


Fig. 25

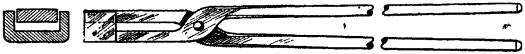


Fig. 26

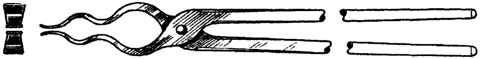


Fig. 27

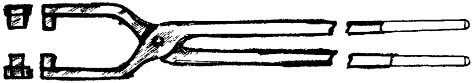


Fig. 28

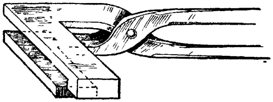


Fig. 29

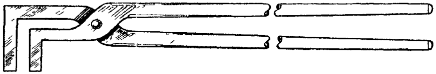


Fig. 30

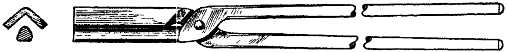


Fig. 31

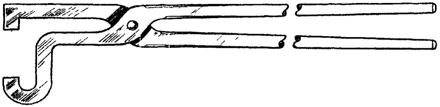


Fig. 32

Figs. 21–32. Various Forms of Blacksmith's Tongs
The examples illustrated are described fully on pp. 174–175

chisel or bolt fits into the bowed portion, thus allowing the body of the chisel or bolt to be firmly gripped in the hollowed mouth.

PINCER TONGS (Fig. 25). This form provides a ready means of making tongs for similar uses to Fig. 24, but they are not so satisfactory.

FLAT BAR TONGS (Fig. 26). The lugs on the sides keep heavy flat stock in alignment with the tongs while being forged, and the latter should be made to fit the various sizes necessary.

PICK-UP TONGS (Fig. 27). These should always be near the anvil, their name implying their use.

HAMMER TONGS (Fig. 28). These tongs are used while dressing or repairing hammers, the turn-down lugs fitting into the eyes of the hammer. For dressing the heads of flatters a similar form of tongs is used with a shorter but wider mouth.

SIDE-BIT TONGS (Fig. 29). Their construction allows the bar to pass along the side of the tongs when required.

DUCK-BILL TONGS (Fig. 30). Called so from their peculiar resemblance when open, they are used for holding bars bent on the flat or for angle iron.

ANGLE IRON TONGS (Fig. 31). These tongs will hold various sizes of angle iron endwise. The upper jaw grips the outside of the angle, while the lower jaw being rounded gives a firm hold to the inside.

ANOTHER FORM OF ANGLE IRON TONGS (Fig. 32). Here a grip is obtained on the whole of the angle iron crosswise.

The Cold Sate or Sett (Fig. 33). This is used for nicking around iron or steel bars in order to sever them. The handle of this tool is usually formed of an iron rod bent around a fullered recess made in the body of the sate, and finished in a loop at the junction of the ends which are then welded.

Although a necessary tool, it is less frequently used in our modern smithies than formerly, as now shears and mechanical saws are at hand to cut the material with greater exactitude.

The Hot Sate or Sett (Fig. 34). This tool is in constant use for cutting away extraneous metal while hot. Hot sates are fitted with wooden shafts. Specially thick hazel rods are to be obtained suitable for these and other anvil tools.

The Gouge (Fig. 35). The gouge is really a hot sate with the cutting edge made on the curve. A number of these are likely to be required with curves of various dimensions to suit the job in hand.

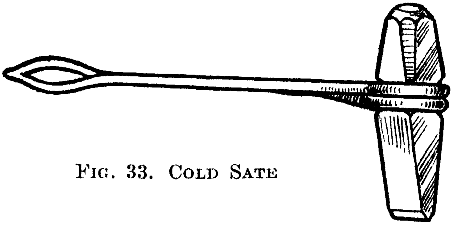


FIG. 33. COLD SATE

The Hardie (Fig. 36). This is made to fit into the square hole of the anvil, and is used by the blacksmith to particularly cut or mark the iron while hot with his hand hammer.

The Flatter (Fig. 37). The purpose of the flatter is for finishing and smoothing the surface after hammering to shape has been completed.

The Set Hammer (Fig. 38) is not used as a hammer, but is struck on the head by the helper while the blacksmith holds it in the position he requires to set down shoulders or smooth out fuller marks near the shoulders before he finishes with the flatter. The set hammers are made in various widths with rounded or sharp edges, and some may have a foot-shaped projection to reach otherwise inaccessible places.

Punches (Fig. 39). Punches of square, round, and oval sections are required in a variety of sizes during forging operations. For hot punching they should have a good taper as in the illustration.

Drifts (Fig. 40). These tools are used to finish the size of punched holes. They are made taper and bulging in the centre ; when forced through the punched hole they make the sides parallel. Their shapes and sizes are as varied as punches. The drift used for finishing the eyes of the tools the blacksmith makes should always be oval in section as at *A*, Fig. 40 ; if made a flattened round as shown at *B*, Fig. 40, the sharp corners cut in and are therefore liable to start fractures.

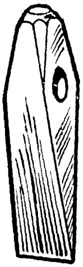


FIG. 34

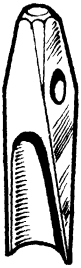


FIG. 35

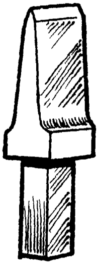


FIG. 36

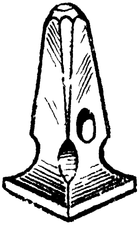


FIG. 37

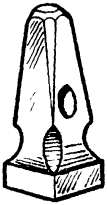


FIG. 38

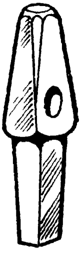
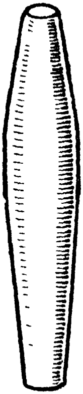


FIG. 39

Fullers (Fig. 41). Fullers are made in pairs, the bottom one fitting into the square hole of the anvil. The top fuller having a shaft is held by the blacksmith.



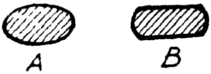


FIG. 40

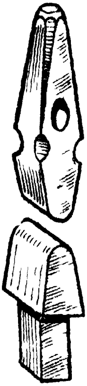


FIG. 41

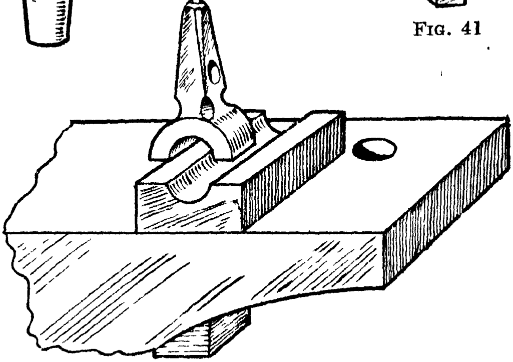
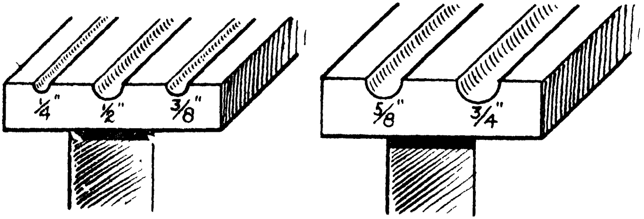


FIG. 42. THE SWAGE

Its operation is one of drawing, and it is mainly used to reduce the metal while making shoulders, and performs this operation very rapidly.

Fullers are made in sizes corresponding with those of round iron bars, viz., ¼ in., ⅜ in., ½ in., ⅝ in., etc.

Swages (Fig. 42). Swages are used to form or reduce the diameter of round parts of forgings, the size also corresponding with those of round iron. The bottom swage fitting in the square hole of the anvil should have one end in line with the inside face of the anvil. This facilitates deep collars or other projections clearing the anvil while swaging.



Figs. 43 and 44. Swage Blocks for Small Diameters

The top swage should always be made independent. Small diameters such as ¼ in., ⅜ in., ½ in. can be made on one block (Fig. 43), and ⅝ in. and ¾ in. can have two (Fig. 44). The larger sizes are better made singly. Fig. 45 shows a plan view of a collar swage, which is made to any desired shape, plain or ornamental. If the collar be on a square bar the swage then takes a V form, the square bar being worked across the diagonals.

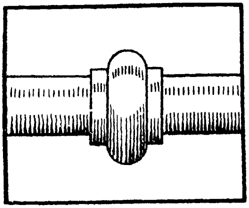


Fig. 45. Collar Swage

FORGING SMITH'S TOOLS

Hammers. To make a hand hammer similar to that shown in Fig. 18, take a bar of cast steel (for smith's tools) 1¾ in. round or octagonal and heat it carefully in the fire, taking care not to burn the steel—

a bright red heat will be right. Then fuller each side of the portion in which the eye will be formed as shown (Fig. 46). Reduce the pane end to $1\frac{1}{4}$ in. diameter, and taper it to 1 in. diameter in $\frac{1}{2}$ in. Now punch the eye to about half way through the steel, using a little coal dust. When punching deep holes, coal dust in the red hot metal quickly generates gas which causes a rebound, thus keeping the punch from sticking in the hole. Of course, the punch must be kept cool by plunging into water. Now turn over and repeat the process on the other side. Having punched the hole, take a drift (as Fig. 40) and drive this first on the one side of the eye, and use a top fuller to spread the metal (Fig. 47) to the dotted lines indicated in Fig. 46; drive out drift and repeat on other side, round off, and finish with the flatter. Of course, during these operations

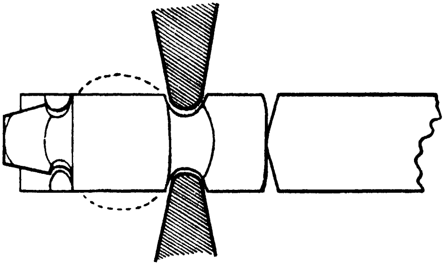


Fig. 46

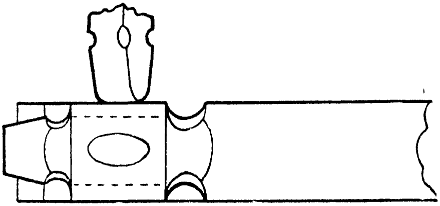


Fig. 47

Forging a Hammer Head

the steel must be heated repeatedly ; do not hammer steel below a dull red heat, otherwise its structure will be injured. The eye will thus be formed larger at the outsides than in the centre, and so when the shaft is fitted and wedged it cannot fly off.

Now cut off from the bar 2½ in. from the centre of the eye (Fig. 46), swage and true up, grind face to have a slightly rounded effect, and round off the pane. Heat the whole evenly and leave in the ashes to cool. To harden, reheat to red, cool the two faces alternately in a shallow trough of water from which the chill has been removed ; when sufficiently cooled rub the faces on a piece of sandstone, and, when the colour reaches a light purple, quench.

The shaft may now be fitted and should be of straight grained ash or hickory thinned between the head and the handle to give spring to the blow. The hammer (see Fig. 18) is now complete ; it is a really comfortable hammer to use, and one a craftsman will handle with pride.

Tongs. The blacksmith frequently finds it convenient to alter his existing tongs to suit another size to that for which they were originally intended. If they are badly made his tongs will be a constant source of trouble to him through repeated breakages. It is wise therefore for his stock of tongs to cover a wide range, and so save time in making unnecessary alterations and repairing breakages. Where a number of articles of unusual shape are to be made, it will be half the battle if he devises suitable tongs to hold the work.

To forge a pair of tongs as Fig. 22, take a piece of 1 in. square bar. Make white hot and bend over the front of the anvil as shown at *A*, Fig. 48. Make a second bend at the end as at *B*. Then hold the bar at an angle on the left side of the anvil and flatten out to ½ in. thick as *C*, Fig. 49. Now place the edge of the flattened portion *C*, Fig. 50 (shown in dotted lines), on the inside edge of the anvil and draw out to ½ in. square. This end can now be scarfed with the rein or handle made of $\frac{7}{16}$ in. diameter rod, and the two welded together at *D*. At the same time chamfer the square corners

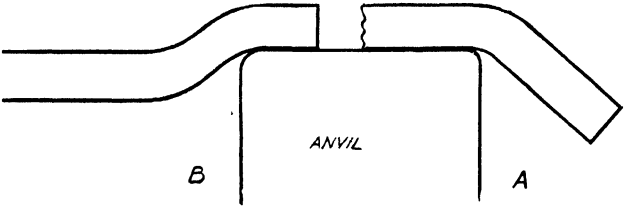


Fig. 48

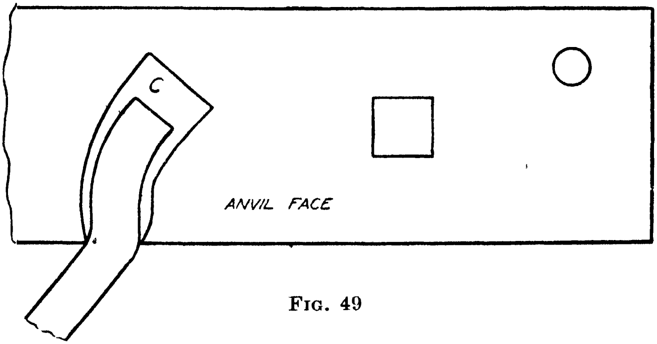


Fig. 49

Figs. 48 and 49. Initial Steps in the Forging of a Pair of Open Mouth Tongs

of the shank. Cut off from the 1 in. square bar sufficient to form the jaw of the tongs, and shape mouth as *E*, Fig. 50, making a fuller mark in the centre (see section *F*, Fig. 50). After forming the jaw, punch a hole for taking a $\frac{7}{16}$ in. rivet. We now have the finished product as shown at *G*, Fig. 50. For the next jaw proceed exactly in the same way, and rivet the two together with a hot rivet. The jaws will be found to be very tight; to loosen, heat them in the fire to a red heat and work the handles backwards and forwards. Set them on a piece of material of required size, and cool in the water trough while moving the handles as before.

Flatter. To make a flatter as illustrated (Fig. 37), take a piece of 1½ in. square smith's quality cast steel and jump or upset the end as at *A*, Fig. 51. Cut off about 4½ in. and place in the 1½ in. square hole of the swage block (the edges of which should be rounded) and spread to 2½ in. square (see *B*, Fig. 51). The next operation is to punch the eye and use drift as Fig. 40. Fullering across the corners between the eye and the face as *C*, Fig. 51, will improve the appearance. To form the head, draw down to about 1 in. square and

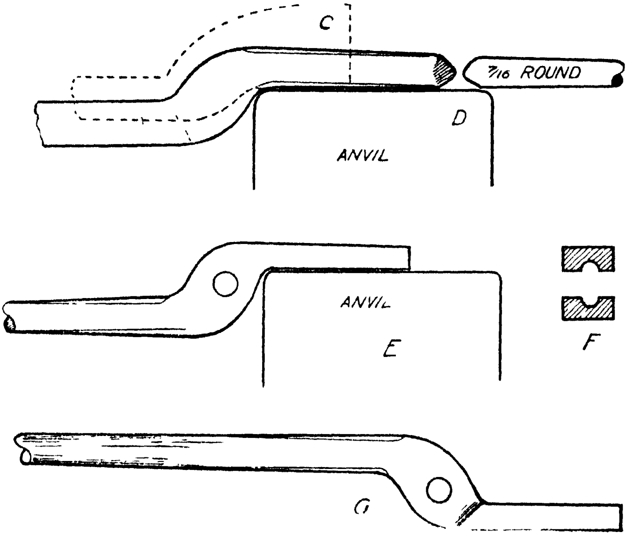


FIG. 50. FINAL STAGES IN THE FORGING OF A PAIR OF TONGS

chamfer the corners as at *D*, Fig. 51. Grind the face level and round off the four edges so that they cannot cut into the metal.

The making of most other top anvil tools has much in common with the above description.

Set Hammers. These are made in a similar manner, omitting the first operation of upsetting.

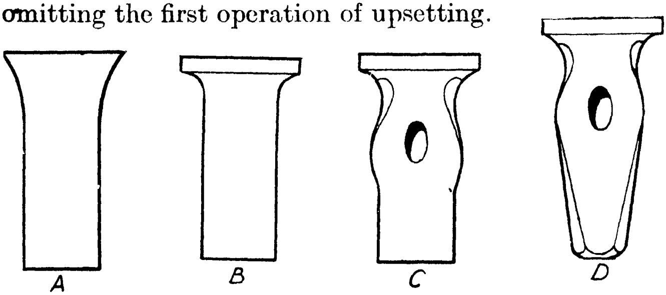


FIG. 51. MAKING A FLATTER

Sates. Sates are tapered before punching the eye, otherwise the eye would get distorted and the steel would receive undue strains in correcting the fault.

Small Fullers. These are generally required wider than 1½ in., so the upsetting of the steel is kept flattened parallel with the eye and formed in a swage to the required size.

Large Diameter Fullers. Fullers of large diameter are made from larger sized steel, a shank being forged to fit a hole in the swage block the same as for the flatter, but instead of spreading the metal four ways it is made lengthwise, the narrow side tapering from the shank to the thickness required to form the necessary size in the swage.

Top Swages. Top swages are made in a similar manner to the flatter, but with a thicker face to take the grooves. These are formed by beating in with a round steel bar before making the eye for the shafts.

Bottom Swages. They are usually made of thick mild steel with the shanks which fit the anvil welded. The grooved portion being thick does not allow the swage to curl up and alter its shape while in use.

HARDENING AND TEMPERING

The hardening and tempering of steel has become a highly specialized art (see Volume III), and in the factories making cutters, taps, and other tools in quantities the tempering is dealt with in a special department equipped for the purpose. Still the blacksmith is in constant demand to temper some tool or other, and it requires a certain amount of judgment on his part to know the nature of the steel the tool is made of, and also what temper is best suited for the work the tool has to do. The term tempering means the grading from extreme hardness to softness.

Annealing. All steel should be annealed before hardening to take away any local strains that may lie dormant in the steel. To do this the blacksmith should make the tool red hot (not white hot) and bury it in dry slaked lime, or, if this is not available, dry ashes, although not so good, will serve. The blacksmith may adopt one of two methods of tempering according to the nature of the work expected from the tool. The first method would be again to heat the tool to red heat and quench in water, moving it about meanwhile. Water used for any tempering should always have the chill taken from it, or a layer of oil may be used over its surface, otherwise ice cold water causes the outer portions of the steel to cool too quickly while the inside of the steel is still red hot, the expansion of which causes minute cracks in the chilled outer shell of the tool.

Letting-down. After quenching, the tool will be found to be dead hard, and requires what is called letting-down or drawing the temper. The face of the tool should be polished and the whole placed over a piece of hot iron, which will cause various tints to appear, varying from straw colour to light blue. These colours indicate the hardness, and the tool is again quenched when the desired colour is reached.

The second method more commonly used, particularly when tempering sates, chisels, and similar tools, is after heating to red, to dip the end to be tempered for about 1½ to 2 in. in the water, polish with a rubbing stone, and allow the heat retained in the body of the tool to bring down the required colour before finally quenching.

One drawback to this method is that if the end is not cooled sufficiently, the temper comes too rapidly, and if quenched entirely the body of the tool being hot causes this portion to be too hard. Slow tempering assists in toughening the steel, while a quick temper tends to make a brittle edge. The blacksmith is also required at times to case-harden articles of iron or low carbon steel.

Case-hardening. This is a means of putting a thin coat of steel on the outside of iron, and thus obtaining a hard wearing surface. This steely coat is usually not more than ⅛ in. thick, while the core inside still retains its original softness. Where case-hardening is required in large quantities, the articles are packed tightly with granulated bone, leather scraps, horse-hooves, etc., or with special patent preparations in iron boxes. These boxes are sealed and made airtight, and kept red hot for the length of time necessary to get the depth of case-hardening required, after which they are taken out and plunged in cold water. The blacksmith's method is simple, and is to bring the work to a red heat in a good clear fire, remove all scale with a scratch brush, and sprinkle yellow prussiate of potash over the surface, and when this has fused to plunge in cold water. If a thick case is required the operation may be repeated several times.

DRAWING AND TAPERING

It appears very easy when watching an experienced blacksmith drawing down a piece of square material, maintaining its true outline as he rapidly turns it backwards and forwards on each of its successive faces. The young blacksmith does not find this operation at all easy. The shape he obtains may be a rhomboid or any other irregular four-sided figure. The illustration *A*, Fig. 52, shows an actual example; to correct such a shape do not try to do so by hitting the work fair and square, but strike the highest corners with the hammer as *B*, Fig. 52, using a drawing motion towards the lower corners, and then turn over and repeat the operation, thus gradually making the square section intended.

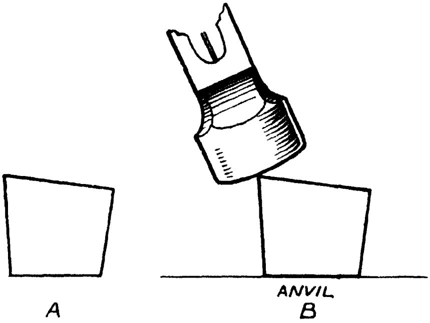


FIG. 52. IRREGULAR SHAPE OBTAINED WHEN DRAWING DOWN

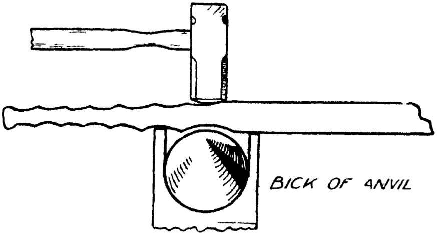


FIG 53. TAPERING BAR IRON

Tapering a bar of iron or steel naturally suggests that the bar will be lengthened, or, to use the blacksmith's term, it will be drawn. To do this the metal should always be given as high a heat as possible without injury to its structure. To draw heavy material on the flat face of the anvil is rather laborious, particularly if a long taper is required ; by using the bick of the anvil a fullering is given to bring the metal roughly to the required size (see Fig. 53). To smooth, the fullering effects are beaten out on the flat face of the anvil and finished with the flatter.

Sometimes the drawing is done in sections, the bar being first drawn to the next smaller section of bar which is then welded on and drawn down, this operation being repeated as often as necessary.

The above remarks do not apply to small sections, as these are quite successfully worked on the face of the anvil.

UPSETTING, SCARFING, WELDING

Upsetting. The process of upsetting, or, as it is sometimes called, jumping, is the means taken to enlarge the size of the section of iron to allow for the wastage, due to the scales which always form when iron or steel is made hot.

Where two pieces of iron are to be welded together the end of each bar is made hot. The extreme end is then cooled and then repeatedly dropped on the anvil, or on a block near by on the floor ; thus the heated portion swells with each successive drop as at Fig. 54. If, as sometimes happens, it is inconvenient to upset as described, the work may be laid on the anvil and the blacksmith's helper would use the backing hammer or the sledge. After reheating, the scarf is then formed. If a collar is to be welded toward the centre of the bar (Fig. 55) the bar is heated at the required part, and as the heated portion will be longer than is necessary it is cooled to suit. The operation as described above is carried on, care being taken to see the bulge is concentric with each end of the bar as Fig. 55, and not as Fig. 56.

When repetition work is in constant demand special machines are used. In these the work is clamped between two jaws of the machine, and as these gradually close together the heated bar swells to correspond, the work being set to make the collar to finished size.

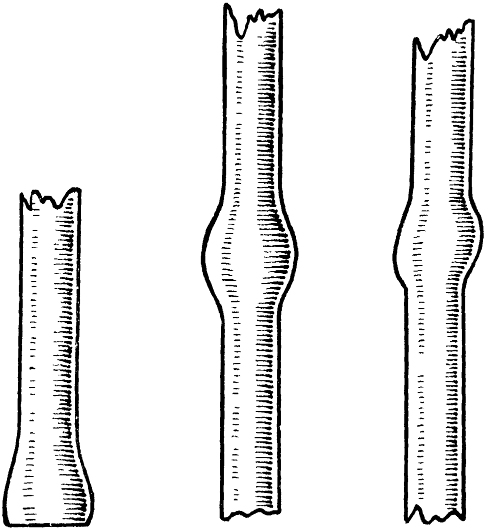


Fig. 54 Fig. 55 Fig. 56

Examples of Jumped Bars

Small sections of iron are usually upset and scarfed in the one operation. The bar is slightly bent over the face of the anvil, the curved portion turned upwards on the anvil (Fig. 57); the hand hammer being used with a pushing motion thickens the metal sufficiently, and the scarf is formed in the same heat.

When welding, no rule can be laid down for the amount of upsetting required. Some blacksmiths do not waste so much as others in getting the correct welding heat, and certain fuels also seem to eat the metal more than others, therefore the blacksmith must depend upon his own judgment.

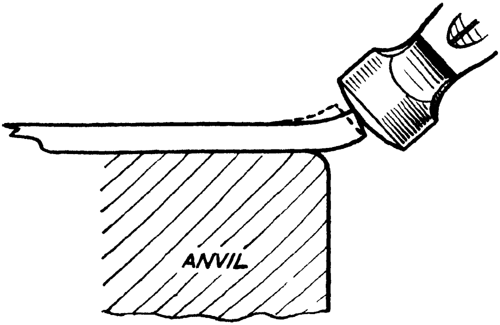
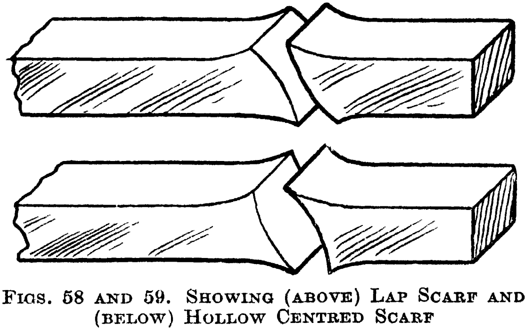


FIG. 57. SIMULTANEOUS UPSETTING AND SCARFING OF SMALL IRON SECTIONS



FIGS. 58 AND 59. SHOWING (ABOVE) LAP SCARF AND (BELOW) HOLLOW CENTRED SCARF

Scarfing. The term scarfing means the preparing of the ends ready for the welding, or what is more commonly called shutting. This preparation is varied according to the nature of the work, and is therefore part of the welding operation. Fig. 58 shows a lap scarf; the centre it will be noted is rounded, which is done to enable any slag, oxide, etc., to be forced out of the joint while hammering. A hollow centred scarf (Fig. 59) will act as a pocket and retain the slag, causing the outside edges only to be welded; it is obvious that such a weld although outwardly appearing perfectly sound is dangerous.

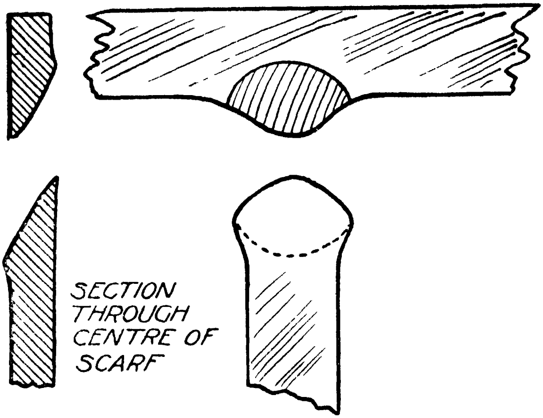


Fig. 60. Scarfing of Tee Weld

A Tee weld, or a flat corner weld, can be scarfed as Fig. 60, shown in plan and section.

If a Tee weld of heavy flat material is required, a slit forming a Vee scarf (Fig. 61) may be made in the edge of the bar while the end of the Tee piece is formed as shown, and when the whole is heated the end is jumped into the bottom of the slot and the Vee scarfs closed in as quickly as possible.

The jump weld, as shown in Fig. 62, is used when building a smaller bar at right angles to the centre of a wide flat bar as in welding the shank to bottom anvil

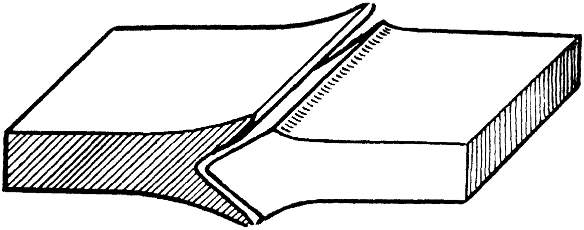


FIG. 61. SLIT FORMING A VEE SCARF

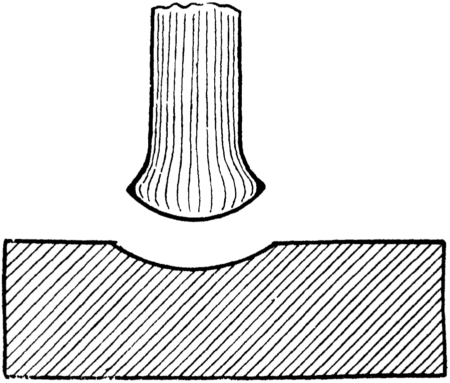


FIG. 62. A JUMP WELD

tools, such as swages, etc. Tee welds on square or round sections may be made by this method also.

Welding. Welding should always be made in a clear fire which has been made free of clinker. The proper heat is when the iron has a liquefied appearance over its outer surfaces. One piece is drawn from the fire by the blacksmith's helper, and placed on the anvil with the end of the scarf slightly over the inside edge of the anvil so that it will not become chilled. The blacksmith then places the other piece in position and secures with a few light taps of his hammer, the helper continuing with the sledge hammer.

While on the subject of welding, mention may be made of fluxes. Their uses are to cover the heated bar with a film of silica which prevents any oxide forming and spoiling the weld.

Many smiths have their own pet fluxes, silver sand and calcined borax being the foundation of most. Bottles crushed to powder have been used by some smiths.

Steel requires a flux fusing at a lower temperature, so a combination chiefly containing borax is used, such as: 20 parts of calcined borax and 1 of iron carbonate; or another, 13 parts calcined borax, 1 sal-ammoniac, 1 prussiate of potash, and ½ part wrought iron filings.

BENDING

Bending a corner seems a simple operation in itself. A sharp bend offers more difficulty than a slow bend. Slow bends are easily made either on a special former or by pulling the iron around pegs fixed in the holes of the levelling plate.

Sharp bends must be forged to suit the work the bend is required to do.

The simplest right angle bend is where a bar (*A*, Fig. 63) is bent on itself to a very short radius. The bar is first heated and cooled to make the short bend to suit the radius in the throat ($A^1 A^1$, Fig. 63). It is then pulled round by hand and trued with the square and left to cool, and, when cold, must again be tested with the square. If the bend is required with the outside and inside throat to have a sharp corner and not rounded, the bar at the point of bending must be upset to allow for the extra material required to square up. If it is attempted to make such a corner without upsetting, the throat becomes checked in, thus forming a crack (see *B*, Fig. 64). Such a corner is therefore useless.

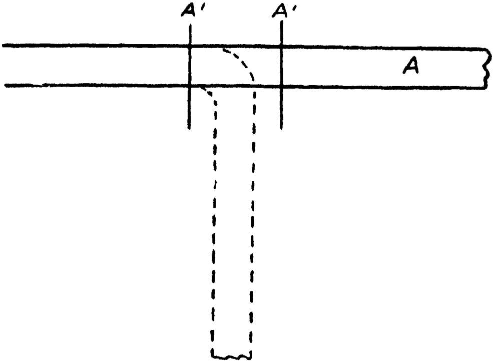


FIG. 63. SIMPLE RIGHT ANGLE BEND WITH RADIUS

A corner from thick material may be required. This if made from the solid requires a great amount of upsetting. The easier method is to use the hot sate to cut nearly through the bar and bend to right angles, leaving the throat slightly rounded (see *C*, Fig. 65). Welding in a piece filling the space left on the outside, shown by section lines (Fig. 65), makes up the outside as shown (Fig. 65). Finish by squaring out the throat with the set hammer.

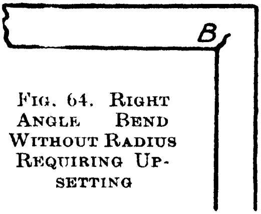


FIG. 64. RIGHT ANGLE BEND WITHOUT RADIUS REQUIRING UPSETTING

A corner with a rounded inside and sharp exterior can be forged by two methods. The first one would be on the lines indicated in making as Fig. 65. In this instance the cut with the hot sate should not be more than half way through the bar, which will allow the throat to have a definite curve when bent to a right angle; when the piece filling the outside space is welded the job will be complete. The other method is shown in Fig. 66. The bar *D* is prepared as shown

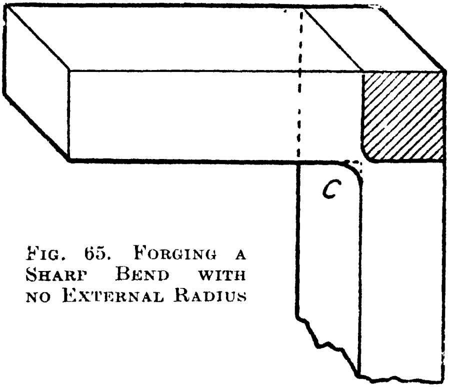


FIG. 65. FORGING A SHARP BEND WITH NO EXTERNAL RADIUS

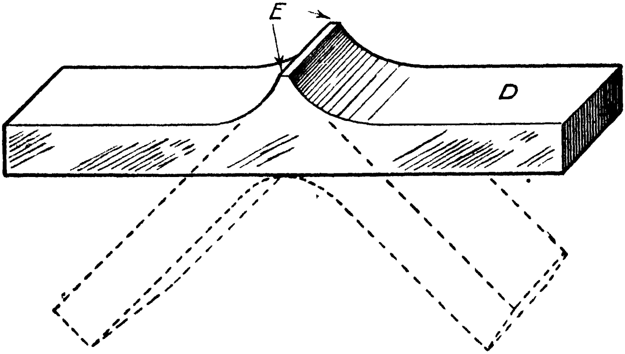


FIG. 66. ANOTHER METHOD OF FORGING A SQUARE BEND WITH FILLET

at *E*, Fig. 66. The dotted lines indicate the form the forging takes when bent at right angles.

THE EFFECT OF TOOLS ON THE GRAIN IN IRON

Where strength is required in forgings that are to be bent, punched, slit or fullered, the continuity of what blacksmiths call the grain, but what more strictly speaking is the fibre of the metal, must be maintained.

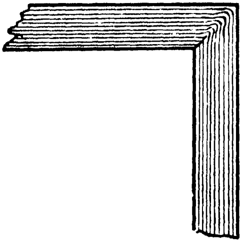


FIG. 67

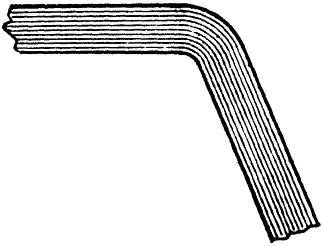


FIG. 68

It is for this reason nearly all smith's tools are rounded, the fuller being an extreme example. The sharp edges are taken off flatters, set hammers, and swages, and even the hand hammer is rounded. Grain or fibre applies to iron more than to mild steel, which, in its structure, may be said to be granular, while iron is truly fibrous.

An example of bending a corner is shown in Fig. 64 in which the fibres at the inside throat were severed in the working. Fig. 67 illustrates how the fibres have been so tightly squeezed into one another that they have ceased to be continuous, and are therefore weak. Had the corner been first bent to an obtuse angle (Fig. 68), and then brought to the square gradually with light successive blows, the fault would have been obviated.

In drilling holes in iron the fibres are separated across the diameter of the hole, but where there is a body of metal this is often not very important. But the blacksmith makes use of holes to attain an object, and therefore for the sake of obtaining strength punches his holes. For punching, the iron is made hot, and the act of punching pushes the fibres aside as illustrated (Fig. 69). The punch is first driven in from one side, then the bar turned over and completed on the opposite side. It will be found that practically no metal has been removed, the hole having made a swelling in the bar owing to the alteration in the position of the fibres.

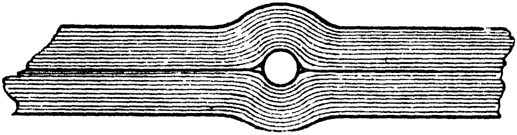


FIG. 69

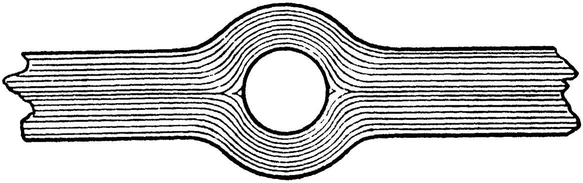


FIG. 70

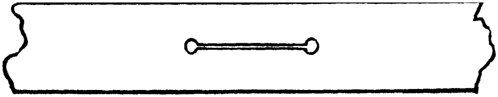


FIG. 71. HOLE SLIT WITH HOT SATE

A hole almost equal to the width of the bar is sometimes called for, as Fig. 70. It is obvious this could not be done by punching one hole, but by making two small holes in the centre line of the bar, spaced to suit the size of hole required by slitting with the hot sate and opening out slightly (Fig. 71). when a few blows on the end as if upsetting will widen the hole sufficiently to take a drift to the size required, thus finishing as Fig. 70.

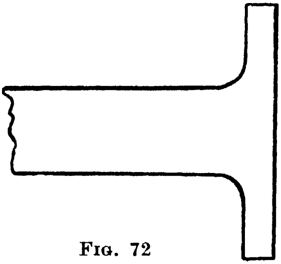


Fig. 72

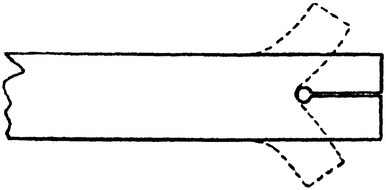


Fig. 73

Punching is a great aid to the blacksmith in making many forgings, such as making a Tee foot on the end of a bar (Fig. 72). He punches a hole and slit through the end of the bar (Fig. 73), and by opening out as shown by dotted lines, drawing down and gradually working the two ends back to right angles he maintains the

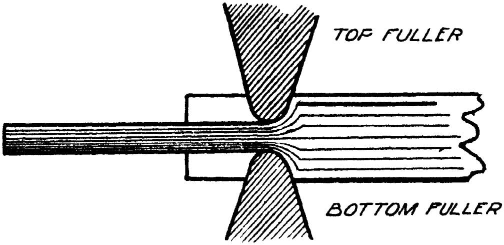


Fig. 74. Showing Fibres Intact After Fullering and Drawing

fibre. Other adaptations of this method will suggest themselves.

While punching maintains the fibre from the inside, fullering is equally valuable as having the same effect on the outside. Fig. 74 shows how after fullering and drawing out, the fibres, though closed in and considerably stretched, are in no way severed.

FORGING VARIOUS FORMS OF HINGES

Hinges are articles of everyday use ; the plain types are usually made by the general smith, but ornamental ones are made by specialists in ornamental ironwork.

Fig. 75 is known as the single strap hinge, and is generally made from $2\frac{1}{2}$ in. × $\frac{3}{8}$ in. iron ; it is fixed at the back of the gate or door. The eye for this type is made by first tapering the end and forming a Vee, as shown at *A*, Fig. 76 ; at about 5 in. from the end it is bent at a right angle as Fig. 77, and then bent over a mandrel *B*, and doubled back as shown in dotted lines in Fig. 77 ; it is then welded to the main strap.

When bending flat iron to form holes, such as the eyes of hinges, the flat bar in bending becomes convex, and thus the two outside ends of the hole are wider than the centre. To counteract this the flat iron is made concave at the part where the eye is to be formed (see section C, Fig. 76) ; by this means the outsides are first brought in contact with the mandrel. In finishing, the centre being full is flattened to the mandrel, thus making the sides of the hole parallel. The Vee at A, Fig. 76, referred to allows an outlet for any oxide, etc., and assists in making a good weld on wide flat iron.

Another form is the double strap hinge which is made to clip the thickness of the wood gate or door : the back strap is often made short, but sufficiently long

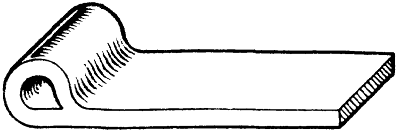


FIG. 75

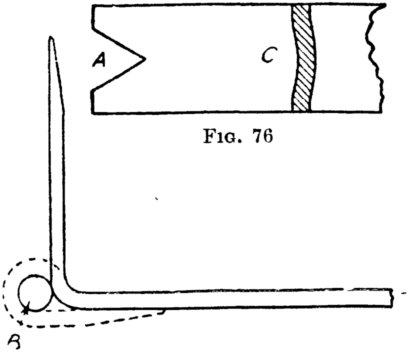


FIG. 76

FIG. 77

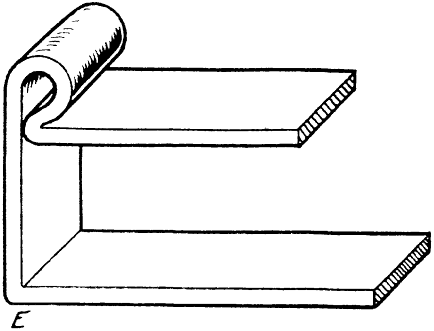


FIG. 78

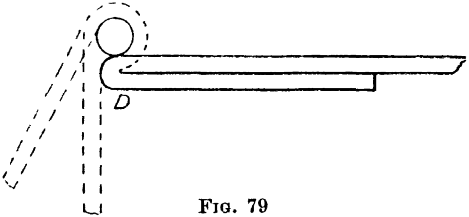
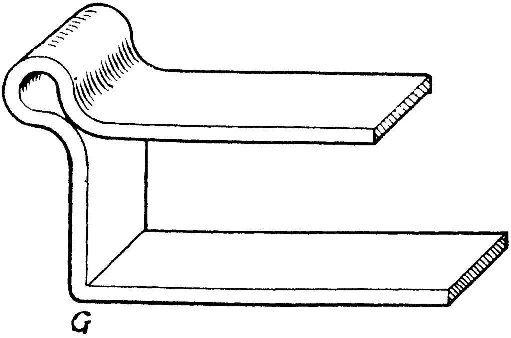
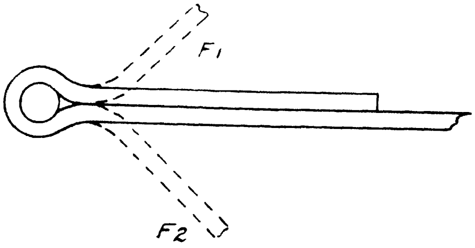


FIG. 79

THE FORGING OF STRAP HINGES

to take a bolt through the style of the gate. The front strap extending along the face of the rail may have some chiselled or simple ornament worked on it. The eyes of these hinges take a variety of forms to suit different openings The form shown (Fig. 78) is made by heating the iron and doubling it over in its own thickness, as shown at D, Fig. 79; after reheating the point *D*, cool the two thicknesses in the trough, and turn over the long face bar and true up on a mandrel. A second bend *E*, Fig. 78, is now made to suit the thickness of the gate.





FIGS. 80 AND 81. FORGING OF ANOTHER TYPE OF STRAP HINGE

Another form of eye is shown (Fig. 80), which is made projecting at 45 degrees from the back corner. The first operation is to form the eye as in Fig. 81, but in order to open each strap to the 45 degrees as *F*1, *F*2, Fig. 81, a spring clamp is required shaped as shown (Fig. 82). It will be seen that these clamp the two thicknesses together behind the formed eye by gripping the whole in the vice. Open out each strap 45 degrees, the two 45's making a square return of 90 degrees, then complete by bending the front strap to suit the thickness of gate as before (see G, Fig. 80).

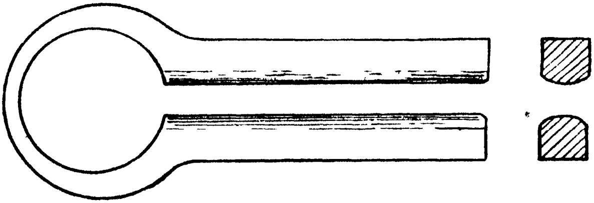


Fig. 82. A Useful Spring Clamp

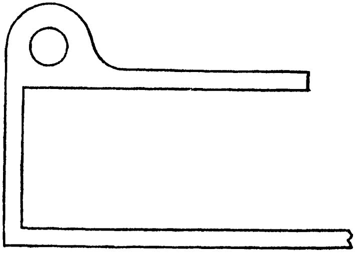


Fig. 83. Forged Solid Eye

In hinges required for important buildings and churches, which often have highly ornamental front straps, the eyes are forged from the solid, thus giving the strength required to carry the heavy doors. If the doors are fitted into stonework the eyes of the hinges may be similar in form to those described by bending,

but if fitted to wood jambs they should be fitted with a flap on the back attached to the hinge with knuckle joints. A forged solid eye to suit the same hanging conditions as Fig. 78 is shown in Fig. 83. To make this, a piece of thick iron sufficient to cover the depth of the eye is fullered as indicated in Fig. 84. The ends are then drawn out as shown by dotted lines. One of these ends must now be bent at right angles and in line with the side of the blob which forms the eye. A small fuller should be used to reduce the curve, as *H*, Fig. 85, and the end worked back gradually as shown again by dotted lines (Fig. 85); complete by bending the face strap to the thickness of the door as before.

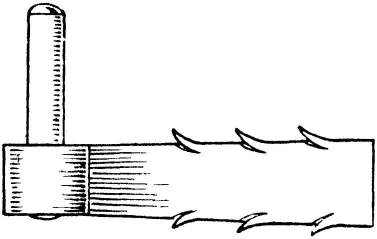


FIG. 89

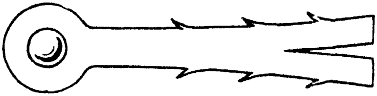


FIG. 90

The forging being complete for the eye, the hole forming this may now be drilled to the size required, and if the face strap has ornaments, such as scrolls, these can be made on a separate piece, and the whole welded to the eye forging just described.

Fig. 86 is the solid equivalent of Fig. 80. To form this a piece of bar of suitable thickness is used. As

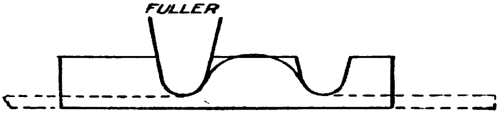


FIG. 84

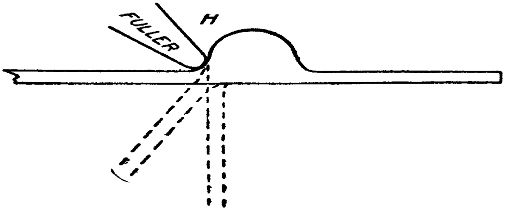


FIG. 85

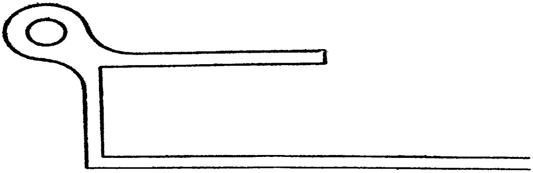


FIG. 86

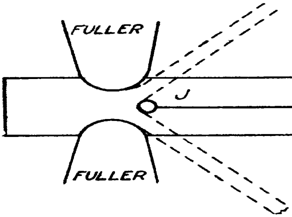


FIG. 87

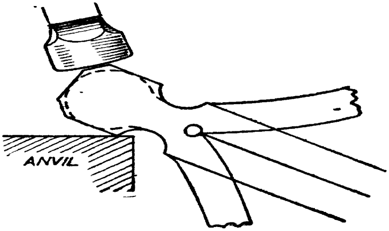


FIG. 88

VARIOUS FULLERING OPERATIONS IN THE MAKING OF THE ARTICLE SHOWN IN FIG. 83

the bar will be rather wide for its thickness and the cutting of the fibre not vital in this case, a small hole may be drilled as at *J*, Fig. 87, and then slit to the end and opened out as indicated in Fig. 88, the neck being formed by a top and bottom fuller shown in Fig. 87. The two outside corners may now be trimmed off with the hot sate, and the blob rounded up on the anvil with the hand hammer (Fig. 88). The slit end may now be drawn out to the required thickness as shown in dotted lines (Fig. 87), and bend for door thickness as before.

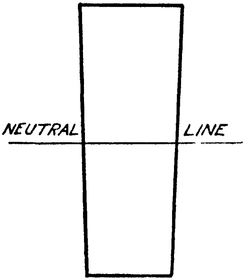


FIG. 91

Hinges of the type described are incomplete without a gudgeon on which to hang them. Fig. 89 shows the kind used when the fixing is in stone, Fig. 90 being a plan view. To make, use, say, a piece of iron $1\frac{3}{4}$ in. × $\frac{1}{2}$ in., and bend flatways forming an eye. A piece of round iron the size required is made hot and driven in the eye just formed and welded as in Figs. 89–90. The ragged ends give greater security to the fixing material.

METHODS OF DETERMINING LENGTH OF MATERIAL IN RINGS

Rings are really one of the simplest shapes the blacksmith is called upon to make, but it has its difficulties as is evidenced by the trouble some blacksmiths have to make one true to size.

The difficulty seems to be in the method taken to get the proper length of straight material required to make the ring to a given size.

In bending, two opposing strains are set up on each

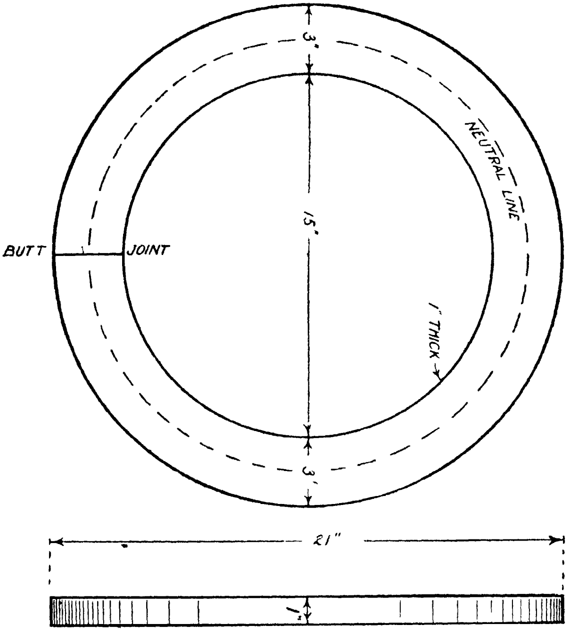


FIG. 92. RING MEASUREMENTS

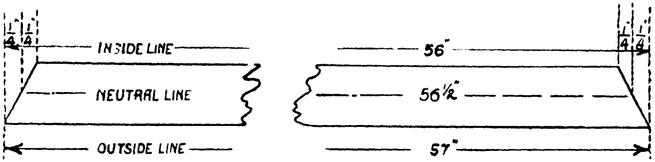


FIG. 93. DEVELOPMENT OF RING

flat rings was taught the writer many years ago, and has proved very useful.

The ordinary ring bent against the flat and showing the thickness of the material is not so complicated to calculate. The neutral must still be the measuring line. The length can be arrived at quickly by adding the thickness of the bar to the inside diameter and multiplying by $\frac{22}{7}$. The blacksmith must then allow the amount necessary for upsetting and welding. For example, with a ring 13 in. diameter made from 1 in. thick bar, the sum would be 14 in. $\times \frac{22}{7} =$ 44 in., plus welding allowances.

The coachsmith uses another method when making a tyre for a wheel ; he has what is called a traveller, which is in reality a circular rule. This is made of a circular piece of metal—which may be marked off like a rule—and has a handle attached so that this circular portion can revolve. It is held lightly while revolving around the wheel, the revolutions being counted. Repeating the operation on the straight bar, and making due allowances, he obtains the length of bar required to surround the wheel.

FORGING EYES

Eyes in a general way may be described as rings formed on the end of a bar. They are more often made of round iron, and take a number of forms to comply with the uses to which they are to be put.

The simplest form is made by bending the end of a bar in ring form as in Fig. 94. Where one or two only are required these may be made over the bick of the anvil by first bending the set-off, as at *A*, Fig. 95, so that the eye will be central with the bar. Now turn over on the bick and bend the end *B*, Fig. 95, while hot round the bick till it meets the corner *A*, Fig. 95.

If a large number are required it is best to make a former as shown (Fig. 96). The first bend *A* is made as indicated, and is held in position while the removable handle with wheel attached pulls the end *B* around the centre boss, which is made to the size required for the inside diameter of the eye.

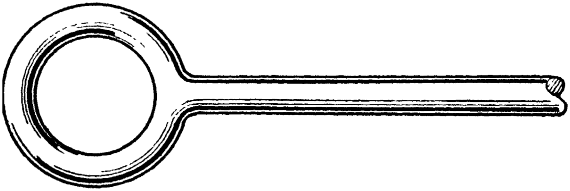


FIG. 99

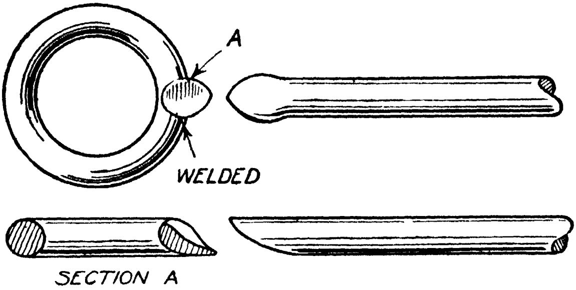


FIG. 100. EYE WITH SCARFED WELDED JOINT

In this way they are produced very quickly and true to size.

Fig. 97 shows the same eye welded at the junction; to do this the end of the bar should be drawn tapering to a square point as shown at *A*, Fig. 98. Form the eye as before, and set the end for welding as Fig. 98. After welding, shape up and finish as Fig. 97. To make a similar eye where the circumference is unbroken (Fig. 99), a ring the size of the eye may be made and welded, and the welded joint scarfed at *A*, Fig. 100. The shank is upset, scarfed, and welded to the ring at this point ; see Fig. 99 for finished appearance.

If the eye is of small diameter as Fig. 101 it is made from the solid ; to do this a collar made of half round iron is welded on the end of the bar, and formed into a solid ball as Fig. 102. This ball is then flattened as indicated by the dotted lines (Fig 102). The hole can now be punched, but to do this a white heat must be taken to prevent the end from splitting ; after punching, the square edges of the hole can be rounded off on the point of the bick and finished to size with a mandrel or drift.

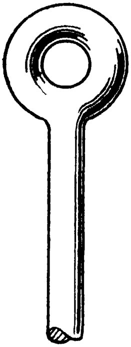


FIG. 101

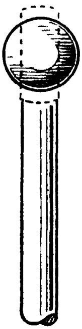


FIG. 102

Solid eyes are often required with a shoulder as Fig. 103, the tenon end being prepared for screwing or riveting.

These are made by using a round bar large enough to form a ball from which the eye is flattened ; the end of the bar is first fullered and swaged to form the shoulder *A*, Fig. 104. Again use the fullers and reduce behind the shoulder as *B*, Fig. 104. Then cut off at *C*, Fig. 104, sufficient to form a ball. This ball is then flattened to the required thickness, and the hole punched as described for Fig. 102. When the hole is rounded up the finished product will appear as Fig. 103.

A similar eye may be required larger than can be obtained from a flattened ball. In this case more material must be allowed than is required to make the flattened ball. When flattened, a small hole as at *A*, Fig. 105, is punched and then slit to the end ; the two slit ends are then opened and swaged to size and bent to the required diameter, and when scarfed and welded the eye is complete.

FORK ENDS

Fork ends are another job where the continuity of fibre must be considered. Fig. 106 shows one formed in the flat; to make this first fuller equally as shown at *AA*, Fig. 107, then draw down one end as shown at *B*, Fig. 108. Make a small hole and split as at *C*, Fig. 108, and open out as indicated by the dotted lines; the two ends must then be drawn out and finished with a flatter as Fig. 109. The two ends that are to form the

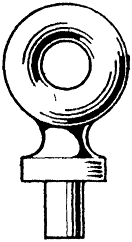


FIG. 103

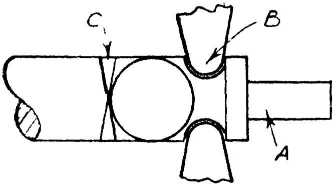


FIG. 104

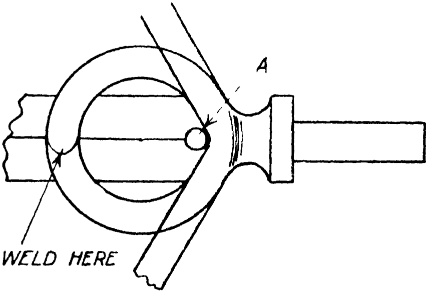


FIG. 105

fork should now be flattened out. the shank being at right angles ; bend these two ends at *DD*, Fig. 110. A piece of steel *E* the thickness of the gap and with the corners of one end rounded can be inserted and the ends of the fork flattened down with a flatter as Fig. 110.

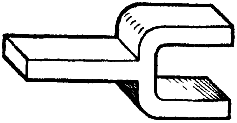


Fig. 106

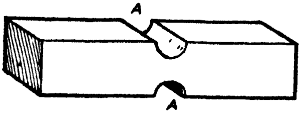


Fig. 107

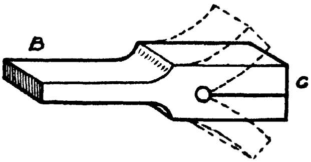


Fig. 108

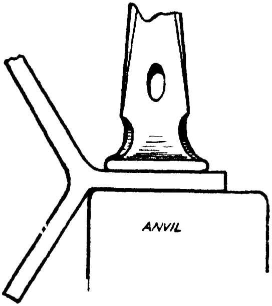


Fig. 109

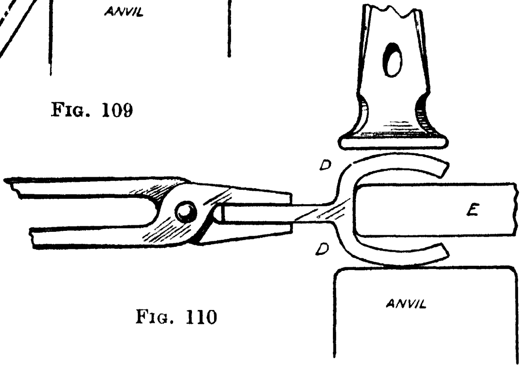


Fig. 110

Forging Fork Ends

A more elaborate fork end is shown in Figs. 111 and

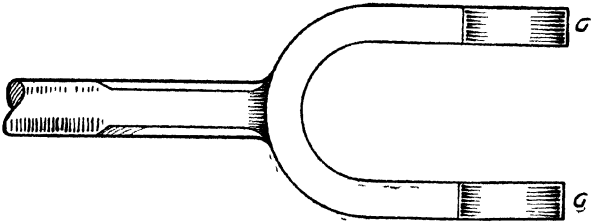


Fig. 111

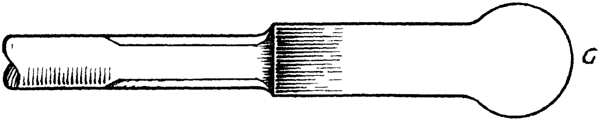


Fig. 112

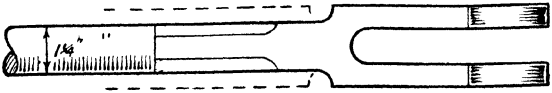


Fig. 113

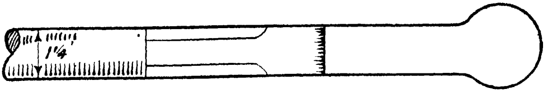


Fig. 114

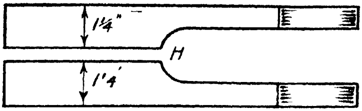


Fig. 115

Various Types of Fork Ends

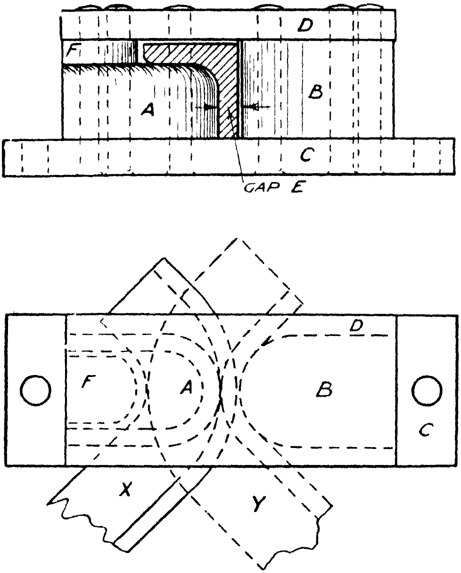
112. To make, proceed as before, but in this case the fullering must be done on all four sides, and the shank drawn down octagonal in section (the shoulder being finished with a small fuller), the round ends being formed in the swages.

Punch, split, and open out as for Fig. 106, but in drawing the ends for the fork leave sufficient metal to make the circular ends *GG*. Bend the ends of the fork, shaping them on a block of the right form and dimensions. Figs. 113-14 show fork ends as used for tie-rods. Taking the tie-rod as 1¼ in. diameter, use 1¼ in. square bar and make two pieces having circular ends and shaped as Fig. 115. Take a welding heat on each and place the shoulders *H*, Fig. 115, together so that the throat does not overlap and then weld. Fuller the wider part shown in dotted lines, Fig. 113, down to 1¼ in. square. A short distance away work the square to octagonal and further on swage to 1¼ in. diameter. The fork end can now be trued to size and the throat rounded off with a piece of steel in the same way as in Fig. 110.

BENDING AND WELDING ANGLE IRON

The bending of angle iron is easily accomplished when a bending machine or rolls are at hand, but where angle iron work is only an occasional job difficulties do appear. In bending angle without appliances, the flat surfaces, being at right angles, take opposing directions. Thus, when bending with one flange outwards, the angle iron endeavours to flatten itself, while bending with the flange inside, the tendency is to crumple. Hence the blacksmith, during the bending operations, must counteract these tendencies. If a corner bend is required to a short radius with the flange either inside or outside, a composite simple bending tool or former as illustrated in Fig. 116 is useful.

To make this, have a cast iron block with the radius of the required bend, but made to fit the inside form of the angle as *A*, Fig. 116, and another block as *B*, Fig. 116, made to the outside depth of the angle iron to be bent. Now secure these two cast iron blocks to mild steel bars *C* and *D*, so that the angle iron can slide easily through the gap *E*. Make a packing piece *F* to clear the thickness of the angle iron, between the block *A* and the bar *D*. Fig. 117 gives a plan view. This tool can be bolted to the levelling plate or other strong support by the holes at each end, Fig. 117. By placing the angle iron while hot through the gap *E* and pulling slowly round, the required curve can be



FIGS. 116 AND 117. COMPOSITE SIMPLE FORMER

obtained with the flange either outside or inside, according to the direction the angle iron is pulled.

An outside flange naturally becomes thinner, while an inside flange becomes thicker, due to contraction,

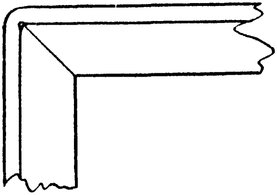


Fig. 118

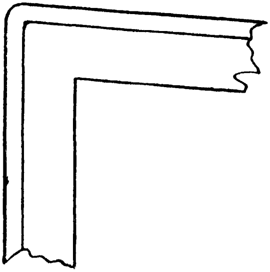


Fig. 120

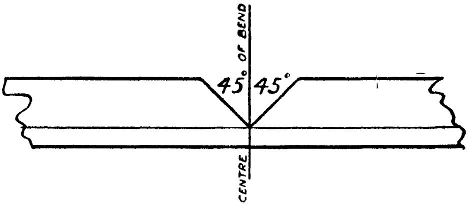


Fig. 119. Square Joint in Angle Iron

so allowance for extra clearance in gap *E* must be made for this.

To make a right angle bend as Fig. 118, cut out a piece at 45 degrees on each side of the centre of the bend as Fig. 119, and if the joint is to butt only, heat the outer flange and bend till the joint meets. If the joint is to be welded more than 45 degrees it must be taken out, and the joints scarfed and then bent round to an acute angle as Fig. 120. The hammering during welding stretches the corner and thus it is brought to a right angle.

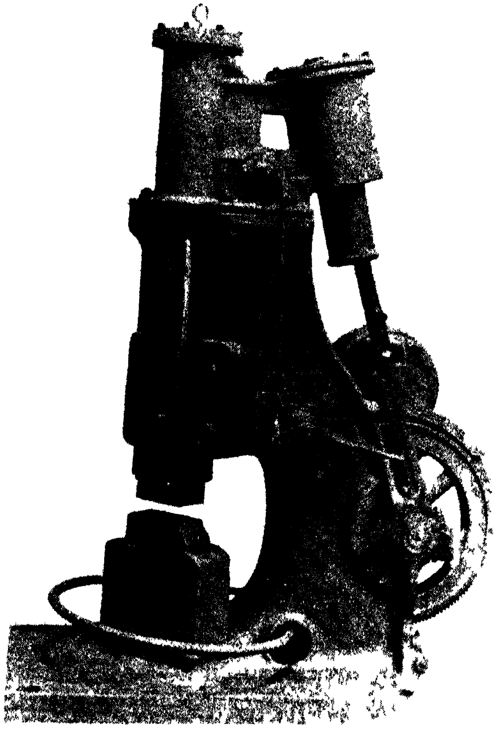


Fig 120a Motor driven Pneumatic Power Hammer

(*B & S Massey Ltd*)

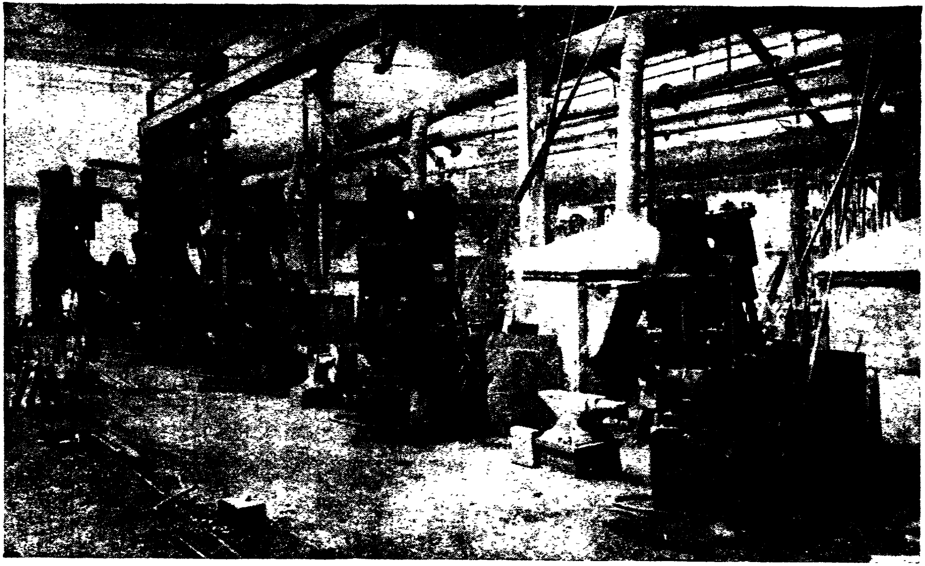


FIG. 120B. BATTERY OF PNEUMATIC POWER HAMMERS
(*B. & S. Massey, Ltd.*)

Long sweeping curves being slow, bends can easily be kept flat while the angle iron is being pulled between pegs inserted in the levelling plate holes and following the required curve.

POWER HAMMERS

For making heavy forgings the blacksmith has machine hammers to assist him. These are of several forms and many sizes designed to suit a great variety of work. Those most frequently used are the steam hammer, the pneumatic forging hammer, and the spring power hammer.

As its name indicates, the steam hammer is controlled by steam and is used in making massive forgings. The piston being double acting, the steam is used both to lift the tup and also to add power to the blow, which is under the complete control of the operator, who can deliver a heavy or a light blow to suit the requirements of the blacksmith.

The pneumatic forging hammer has come into great favour of late years. one of its advantages being that it is driven by a belt from any convenient power shafting or by a motor incorporated (see Fig. 120A).

These hammers have two cylinders, one to collect and compress air which is conveyed to the other cylinder carrying the tup, the operation generally resembling that of the steam hammer. Some of these hammers have also a foot-lever which enables the blacksmith to dispense with an operator and control the blow to suit himself.

The spring power hammer is also belt-driven and is designed to operate a spring arranged to multiply the strength of the blow; an adjustable crank will lengthen or shorten the stroke to suit various jobs.

The tools in general use with these hammers have similar uses to those used on the anvil, but their forms

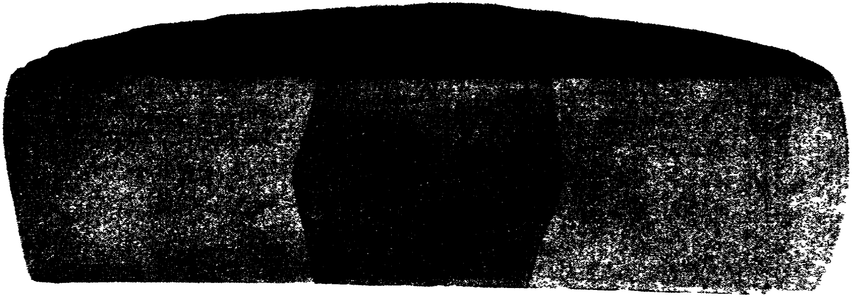


FIG. 120C. SHOWING THE EFFECTS OF LIGHT HAMMERING

A disc of 0·6 per cent carbon steel with inserted piece is shown. Originally, this disc was 6 in. high by 8 in. diameter, and was hammered under a pneumatic hammer. 300 blows were required to flatten the disc to the form shown, and the resulting structure shows that, whilst the forging was much too large for the hammer, the blows were penetrating, and more work was done in the centre than on the surface

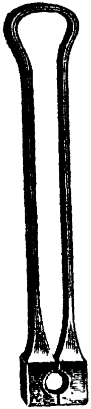


Fig. 121

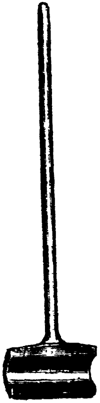


Fig. 122

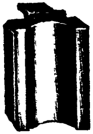


Fig. 123

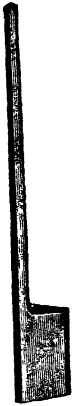


Fig. 124

Fig. 125

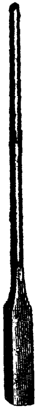


Fig. 126

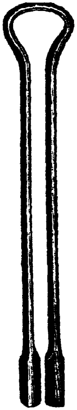


Fig. 127

Various Tools Used in Connection with Power Hammers are adapted to suit their altered conditions. Fig. 121 shows a plain spring swage. Figs. 122-123 show a top and bottom swage. Fig. 124 is called a hot cutter. Fig. 125 is a tool for shouldering. Fig. 126 is a flatting tool. Fig. 127 is a spring necking tool. Messrs. Alldays and Onions supply these tools with their forging hammers.

For the making of certain forms in quantities there is another machine type known as a forging machine. This machine is composed of a row of prepared swages and dies, operated from an eccentric shaft. The swages and dies are arranged to follow the series of operations required to make each individual article.

The power hammer as a modern means of reducing heavy material is not pure anvil work. Hand forging of necessity has variations which do not comply with the present-day standardized requirements. Often a forging will be roughly formed on the ordinary anvil and finished to size with standard dies under the power hammer. On the other hand, the forgings may be roughed out under the power hammer and finished on the anvil by the blacksmith.

ORNAMENTAL IRONWORK

The love of beauty is inherent in the heart of every normal person. Iron from its nature lends itself to enormous variety in this branch of the blacksmith's art. From the making of a simple scroll to the most elaborate of foliate work causes admirers to gaze in wonderment at the skill of the artist craftsman who forms them.

It is the work of the blacksmith art craftsman that gives to the person possessing a piece of this work a feeling of gratification in owning a thing of beauty which it is said " is a joy for ever." This is exemplified in our rural districts, where the village blacksmith, having lost much of the work he formerly did for the farmer through the introduction of mechanical traction and chilled castings for his implements, is now supplying the demand for hinges, latches, door-knockers, fire dogs and fire irons, gates, balconies, etc., called upon for the villas and bungalows being built near the old villages

The first piece of ornament our village blacksmith is likely to try his hand on is a scroll.

The single scroll, Fig. 128, may be likened to a shell in outline, its formation starting small in the centre and the convolutions gradually widening towards the end.

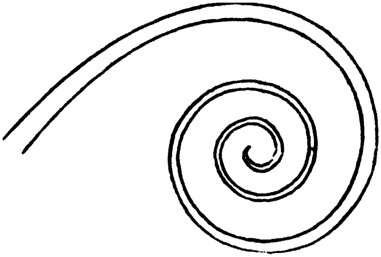


FIG. 128. SINGLE SCROLL

These are made by drawing the end of a bar to a taper, turning the end over the front of the anvil as in Fig. 129, then turning it over as in Fig. 130, giving a few skilful taps with the hammer and rolling up to form the centre, as illustrated by dotted lines, Fig. 130. This operation looks very simple when watching a skilled worker doing it. It requires practice to acquire the art and get the curves required to hook correctly into the scroll former, which is the tool used to complete the scroll. Fig. 131 illustrates this former; it will be seen that being raised in the centre it takes a spiral form, which allows the end to hook easily, the scroll being pulled around the slope, and then flattened. To complete and set the scroll, a scroll fork is used, the design of which is shown in Fig. 132. This also has a companion bottom tool seen in Fig. 133, which will fit either across the square hole of the anvil or in the vice, and is used when setting the completed scroll into the space which it is intended to fit.

The welding of two or more scrolls together is done before finally bending, by sticking the two scrolls together, then scarfing and welding a length to complete the scroll as shown in Fig. 134. The shape *A* at the junction of the two scrolls is important, as will be seen when the scroll is rolled up on the former ; the joint will take a natural spring from the main stem as seen by the dotted lines, Fig. 134. Subsequent welding and the completing of a scroll depends on the design (see Fig. 136). The method of using the scroll forks for finally setting the scrolls is illustrated in Fig. 135. Fig. 136 shows a design for a panel of stair balustrade, the scroll work of which has water leaves inserted. These were frequently introduced during the seventeenth and eighteenth century periods ; they are made

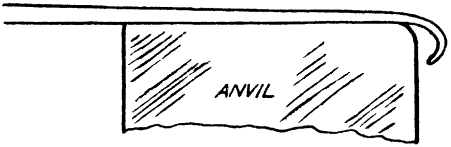


FIG. 129

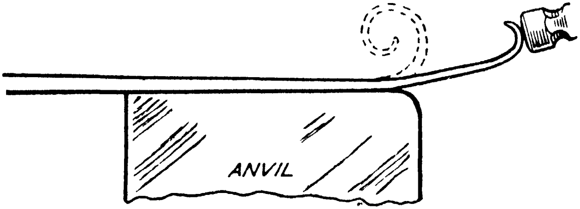


FIG. 130

by cutting a flat sheet as outlined in Fig. 137, bending and hollowing over the bick or on a Vee-stake, as shown

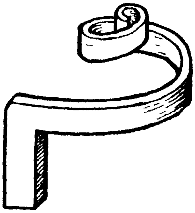


Fig. 131

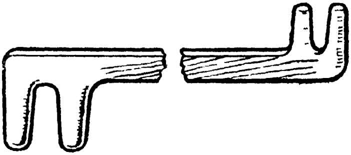


Fig. 132

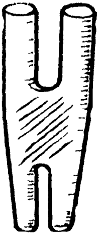


Fig. 133

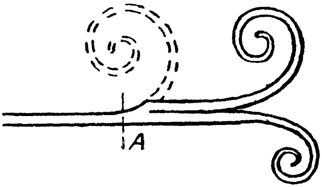


Fig. 134

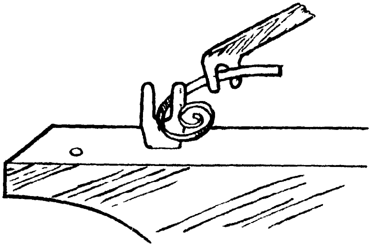


Fig. 135

in outline at Fig. 138, the crimping on the edges being put on before finally welding them to the scrolls.

The twisted bars shown on each side of the scroll panel on Fig. 136 make a nice ornament if the twist is made regular. These are best made by sliding the bar into a length of gas barrel, slightly larger to allow for the increased diameter when the bar is twisted. Grip one end of the bar in the vice, and turn the other end with a tap wrench and thus twist the bar. Large sizes of iron will require an even heat, otherwise the twist would be very irregular and unsightly; either square or flat bars can be done in this way.

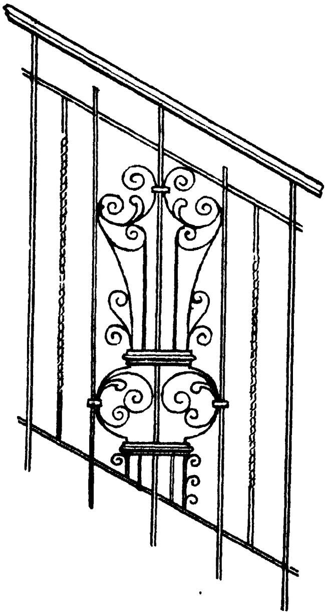


FIG. 136. DESIGN FOR PANEL OF STAIR BALUSTRADE

Another twisted shape, known as a bulb twist, is shown in Fig. 139. This may be used as a handle for a poker or shovel, or a terminal for fire dogs, etc.

The size and purpose of the bulb will determine the sizes of the material to be used, but the method of making depends on the skill of the craftsman to produce even curves.

First swage a piece of, say, 1 in. round down to $\frac{11}{16}$ in. diameter for about 4 in. long (see Fig. 140). Now cut into sections as indicated by the lines, making five pieces marked *A*, *B*, *C*, *D*, and *E*. Cut off eleven pieces of $\frac{3}{16}$ in. diameter mild steel rod 5 in. long, and surround the centre pieces, *B*, *C*, and *D*, with these eleven rods, holding them by a couple of steel wires twisted tight, but seeing there is a space between each centre piece. A pair of hollow bits, held by a coupling, will hold them in the fire while welding. Heat the end *E* in the fire and insert it in one end of the bunched rods, and then gently heat to welding heat in a clear fire,

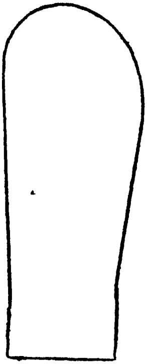


Fig. 137

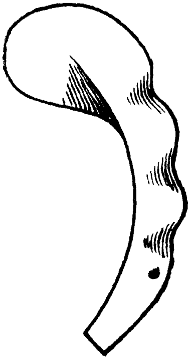


Fig. 138

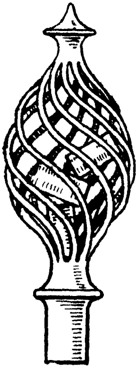


Fig. 139
Bulb Twist

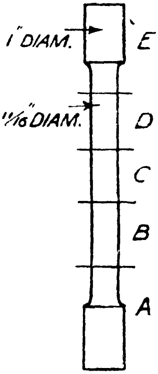


Fig. 140

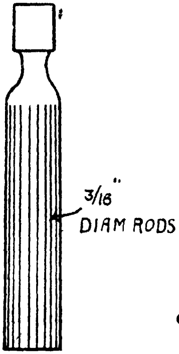


Fig. 141

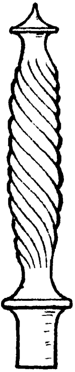


Fig. 142

care being taken to keep the loose end in position. To do this, a bend on the end of the poker may be found useful. When this end is welded in, use a fuller to reduce the neck as in Fig. 141, and repeat the operation on the other end. Now heat the whole of the rods evenly to a bright red, and by holding one end in the vice twist tightly with a pair of grips on the other end ; this will tighten the loose pieces, *B*, *C*, and *D*, which were inserted in the centre (see Fig. 141). The pointed end and the collar shape at bottom can now be formed. Again heat the twisted rods evenly and twist in the opposite direction, slightly pushing the ends toward each other. The purpose of the three loose pieces in the centre can now be seen as they collapse. They can now be removed and the curves trued up by setting with a slender punch through the interstices.

The above merely introduces this portion of the blacksmith's art, but the blacksmith who interests himself in ornamental work cannot do better than visit the iron gallery of the South Kensington Museum. He will be astounded at the many uses ornamental iron has been put to, and also at the variety of decorative effects that can be obtained in this, the most common of metals. There he will see examples of English ironwork from the twelfth to the eighteenth century, and be able to compare these with the work of other countries, which is also represented. The variety and excellence of the examples shown will create wonderment at the skill of the craftsmen of these early periods.

SECTION XXIII

WELDING

BY

W. HEIGH

SECTION XXIII

WELDING

Of the many methods adopted by engineers to aggregate simple standard rolled plates and sections into the intricacies of shape demanded by modern structures, that of welding the parts is the most attractive. Using modern welding processes, the joints are almost indistinguishable from the parts joined so that in effect the assembly is transformed into a single unit, and, if the metals of the parts and the weld are skilfully placed in the paths of stress, the balance of the whole unit—stress to structure—can be obtained as by no other method of construction.

Smith or *forge welding* is the oldest form of such a joint. The smith heats the parts, two at a time, at the ends or edges that have to be joined and then hammers the heated parts together (probably after scarfing them to make sure of sufficient area in the joint and also to ensure uniformity of section across the weld). Typical smith welds are illustrated in Fig. 1, although there are many variations in form and practice.

During the past forty years two quite different methods of welding—*gas* and *arc welding*—have been developing side by side. As in forge welding, the metal is heated at the place where the joint has to be made, but the temperature of this metal is so high that it flows into the joint so that each part furnishes a portion of the joint or weld metal, and no hammering or pressure is required. Smith welding is carried out at forging temperature when the metal is highly plastic, and the other two methods of welding just mentioned are carried out at molten temperatures; smith welding is one of a group of welding processes which we call the **plastic** processes, and the others are typical of a second group, the **fusion** processes.

The chart, Fig. 2, classifies all the best known processes of welding into these two groups. The tabulated entries also indicate the means used in each process for obtaining the weld. It will be noted that no provision is made for pressure or hammering in the fusion group.

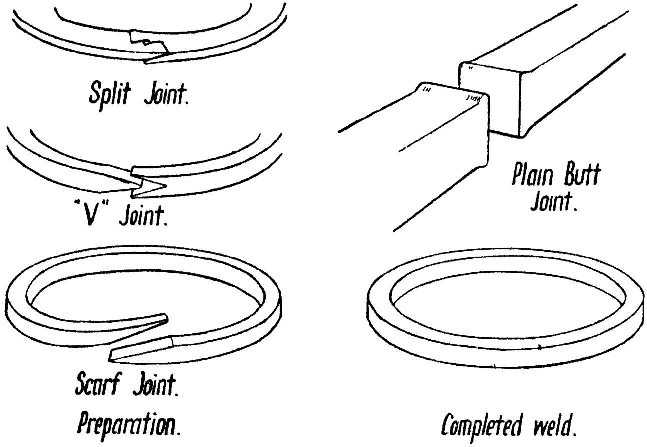


FIG. 1. TYPICAL SMITH WELDS

HEAT AND TEMPERATURE

In all welds the metal local to the joint is heated. Both the *temperature* and the *rate of heat supply* are important. The temperature decides whether pressure is required to make the joint; in plastic welding the temperature is that required for forging, say 1150° C. maximum for mild steels; in fusion welding the molten metal is certain to be above the melting temperature (i.e., $>$ 1450° C. for certain steels and $>$ 1500° C. for others). The rate of heat supply will decide how

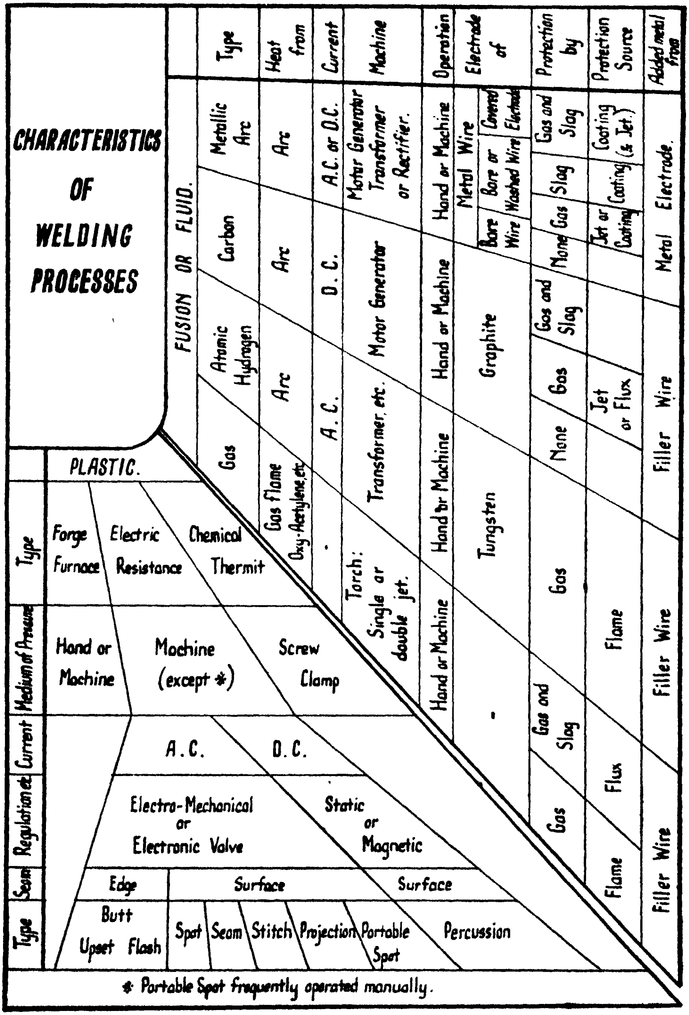

CHARACTERISTICS OF WELDING PROCESSES
FUSION OR FLUID.
Type
Heat from
Current
Machine
Operation
Electrode of
Protection by
Protection Source
Added metal from
Metallic Arc
Arc
A.C. or D.C.
Motor Generator Transformer or Rectifier.
Hand or Machine
Metal Wire
Covered Electrode
Bare or Washed Wire
Bare Wire
Gas and Slag
Slag
Gas
None
Coating (& Jet.)
Coating
Jet or Coating
Electrode.
Metal
Carbon
Arc
D. C.
Motor Generator
Hand or Machine
Graphite
Gas and Slag
Atomic Hydrogen
Arc
A. C.
Transformer, etc.
Hand or Machine
Gas
Jet or Flux
Filler Wire
Gas
Gas flame Oxy-Acetylene, etc.
Torch: Single or double jet.
Hand or Machine
Tungsten
None
Gas
Flame
Filler Wire
Hand or Machine
Gas and Slag
Gas
Flux
Flame
Filler Wire
PLASTIC.
Type
Medium of Pressure
Current
Regulation etc.
Seam
Type
Forge Furnace
Electric Resistance
Chemical Thermit
Hand or Machine
Machine (except *)
Screw Clamp
A.C.
D.C.
Electro-Mechanical or Electronic Valve
Static or Magnetic
Edge
Surface
Surface
Butt Upset Flash
Spot
Seam
Stitch
Projection
Portable Spot
Percussion
* Portable Spot frequently operated manually.

FIG. 2

quickly the required amount of metal (along the whole joint) can be heated, and twice the rate for a given purpose might be expected to double the speed of welding (if other factors, such as the depth to which the heat has penetrated, remain equal).

It is obvious, therefore, that the *source of heat*—whether it be a coke fire, an oxy-acetylene flame, or an electric arc—must have a temperature above the melting temperature of the metal being welded; and it will be readily appreciated that the margin of temperature between the source of heat and the weld metal must be sufficient to allow for some dissipation of heat and loss of temperature due, for example, to conduction into the surrounding colder metal and radiation into the atmosphere. Thus the relatively cool flame of an open coke fire or a water gas flame will raise metal to the plastic weld temperature, but the fusion weld requires the high temperature of the oxy-acetylene flame, the welding arc or burning thermit.

The rate of supply of heat varies widely even between processes in each group. In the plastic group the coke fire and the water gas torch supply heat fairly rapidly in certain circumstances, but in comparison with the rate at which resistance welding of like joint sections can be carried out these others are very slow indeed. Not only does resistance welding obtain, by very high electric current, a very high rate of heat supply, but it also concentrates the heat into a relatively small amount of metal.

Also, in fusion processes of welding such as the metal arc and carbon arc the *concentration of heat* is more intense than in gas welding or atomic hydrogen welding, so that the heat energy is used more economically; in addition, the temperature of the arc is higher than that of the oxy-acetylene flame, and the rate of supply of heat can be raised very much higher.

Generally, rapid production and economy of labour can best be obtained by using the source of heat that is of the highest temperature, is of the most concentrated form, and has the highest rate of heat energy supply. For this reason resistance (particularly flash) welding and arc welding are the most popular of all the welding processes each in its group, because they both, for the reasons just stated, weld more rapidly and economically than the other processes in their group.

On the other hand, a certain reservation must be made because in certain cases the temperature or the quantity of heat obtained in resistance or arc welding may be too high: thus, in the fusion welding of aluminium the fairly low temperature and comparatively dissipated heat in the flame of oxy-hydrogen is sometimes as economical for thin sheet as hotter and more concentrated sources of heat.

SCALE AND OVERHEATING IN CERTAIN PLASTIC PROCESSES

Even cold steel rusts in air, and, as the temperature rises, the rusting or oxidation takes place more rapidly. At forging temperature this oxidation takes the form of a dull skin or "scale" that quickly appears over the bright red surface. If this scale is squeezed into a welded joint by a hammer or by pressure, a weak section is formed across the joint, and the scale cannot be expelled or the weakness wholly eliminated by hammering or great pressure. Such scale must be cleaned immediately before the pressure is applied.

Smith welding is typical of the plastic processes in which the cleaning of the hot scale is particularly important. In resistance welding (including spot and seam welding) it is only necessary to clean the surfaces before heating because the speed of the whole operation combined with the closeness of the contact throughout the heating and the squeezing prevents scale (which requires oxygen and time) being formed in harmful quantities. In flash welding there is a continuous violent expulsion of air from the tiny gap during the flashing period, and this may explain why such a weld is free of this defect.

Overheating should also be avoided in plastic processes. If the metal is raised to too high a temperature, and kept at that temperature for too long a period, certain effects are observed. In most metals the grains grow in size and large grain metal is rather weak, but mild steel may weaken more seriously (at higher temperatures or with longer times at too high temperatures) owing to what is called "burning." This is not the actual combustion of the metal, such as takes place in oxygen cutting, but is a process of surrounding the grains with weak boundaries, like weak cement around good strong stones in a wall. The whole surface of the metal may look good, but it will fracture readily along the weak inter-granular surfaces. After overheating to this extent the metal cannot be restored by any curative "heat treatment"; it must be re-melted before it becomes good steel.

Thus, entrapped scale and overheating are faults to avoid in plastic processes, and modern processes furnish simple means for their control. Distortion and chilling are two further problems that the plastic share with the fusion processes; they are examined later.

PROBLEMS IN FUSION PROCESSES

The fusion processes are influenced much more than the resistance processes by the knowledge of the craftsman. Some measure of automatic control is attempted in all of the resistance processes, each of which is almost entirely a simple machine operation from the workshop point of view. Thus the operators require skill in only a restricted number of "motions" and are frequently employed on repetition work. In contrast the knowledge of the fusion processes possessed by the operator and his foreman has a large effect on the efficiency of their work.

Some of the fundamentals of the fusion welding processes are peculiar to each single process or to a sub-group, and these particular items in the knowledge the user should possess are detailed later under the appropriate process heading. At this stage certain more general features can, however, profitably be considered in order to emphasize the differences between the two major groups, and as a general background for the particular details that will be added later.

(1) *Oxidation* (rusting and scaling) occurs in fusion as in resistance welding and tends to be even more extensive and rapid as the melting temperature is approached and reached. It is essential that this scale be removed from the heart of the weld and fusion surfaces; in practice it has to be floated to the surface or prevented or destroyed by chemical means, or in some cases it is (seldom very successfully) mechanically scraped off the metal in the course of welding. The cleaning of light oxides (e.g. steelwork scale) from the metal before welding is seldom necessary in fusion processes.

In welding mild steel in air without any protective slag or atmosphere (as in bare wire arc welding, for example) the scale is observed to melt before the metal and to float on its surface. In this case the melting point and density of the scale, being lower than those of the metal, may remove a large amount of the oxide to the surface of the weld. At best, however, such a weld is still tainted seriously with iron oxide inclusions.

In all the modern fusion processes the formation of this oxide is prevented by fundamental elements in the process; or, as expressed above, the presence of scale is prevented or the scale is destroyed by chemical means. Two methods are used for this purpose, by introducing materials that at molten temperatures form in one method a slag and in the other method a gas that surrounds the weld and excludes oxygen from it. In some methods of welding, slag and gas form together a still more effective protective agent. The slags must always have the lower melting point and density, compared with the metals, that are noted above as characteristic of scale.

This serious problem of preventing or eliminating iron oxide is met successfully by modern processes such as covered electrode arc welding, oxy-acetylene and atomic hydrogen welding, and indeed by all the fusion processes in which measures for control of the oxygen absorption are inherent or are introduced.

(2) *Gas Solubility.* Certain metals have the capacity of dissolving certain quantities of certain gases, the quantity dissolved in each case depending on the temperature of the metal as well as the kind of metal. Important examples are oxygen in steel, hydrogen in steel, and oxygen in copper, and an interesting example of less importance to the present study is oxygen in silver.

We have already considered the visible result of the combination of oxygen with hot iron in the formation of scale. A more subtle and invisible effect is also produced when molten iron comes in contact with oxygen. Some of the molten iron combines with oxygen to form an oxide quite different from those mentioned above, and this oxide may dissolve in the steel as a new alloy that, when it cools, is hard and of reduced ductility. This absorption of gas is, however, successfully controlled by the same measures as are used to control the formation of the oxides already referred to; the contact between molten iron and oxygen is prevented by slag or gas, or both, and the oxygen content of the metal is thus kept to a minimum. Also molten iron dissolves large quantities of hydrogen (if present), and as the metal cools it comes out of solution. It is always necessary during cooling to make certain that the gas is given time to float out of the metal before freezing takes place. Otherwise the escaping gases are entrapped by the freezing metal forming pores that weaken the weld and are believed to be accompanied by such severe internal stresses that individual pores are sometimes surrounded by hair cracks that are starting points for major fractures. By simple precautions in the practice of the fusion welding processes this porosity can be prevented in the metals that tend to be affected in this way.

Copper is also very susceptible to attack by oxygen, and special measures have to be taken to keep this under control. The effect in this case is that oxygen and copper combine to form a cuprous oxide which migrates to the grain boundaries to form weak intergranular planes along which the metal fractures readily. The attack of oxygen on copper welds is prevented in modern processes by using protecting fluxes and gaseous atmospheres.

The amount of gas absorbed by any metal depends on the nature of both gas and metal and on other conditions such as the temperature of the metal, but may amount to several volumes. The capacity of silver to dissolve oxygen is quite extraordinary, as the molten metal can in this case dissolve twenty-two times its own volume; this exceptional example is of only passing interest for present purposes, but it may emphasize the importance of understanding the gas-absorbing characteristics of any metal that is offered for welding.

Generally speaking, modern fusion welding processes are designed to keep the absorption of gases in check because the presence of gases almost if not quite invariably weakens the weld, sometimes seriously.

(3) *Chemical Content.* Although mild steel is so easily welded that it is seldom considered as presenting any real problems or difficulties to the welder, this metal can be used to illustrate a third fusion welding problem. Mild steel is composed mainly (about 98·5 per cent) of iron, but it also contains other constituents that impart desirable properties to the metal. The proportion of carbon may be 0·25 per cent, and the steelmaker has almost certainly obtained this quantity by deliberate measures to keep the carbon content from being too high or too low, because very small variations in carbon alter appreciably the strength of the steel. Manganese also will be present in definite quantities (say 0·6 per cent), and will have been carefully controlled by the manufacturer in the course of steelmaking. The inclusion of such quantities of carbon and manganese improve on the strength of pure iron by at least 30 per cent. The weld metal as well as the steel must include these constituents in suitable proportions.

Other constituents that are harmful and the amounts of which are kept as low as possible, although they cannot be wholly eliminated, have to be taken into account in welding as well as in steelmaking. Such undesirables are sulphur and phosphorus. Both are kept below certain permissible proportions which may be 0·04 per cent for each in certain steels but may be 0·06 per cent in others. In addition, the precaution is taken of making certain that the sulphur is distributed through the steel in a harmless form by ensuring that there shall always be sufficient manganese to combine with the sulphur and disperse in a harmless slag.

(This last-mentioned is an important function of the manganese in a steel, both parent and weld metal.)

There are other constituents in the steel of varying importance, but usually of smaller quantity and of less importance to the quality of the steel than the constituents already referred to. Just as the gas content is controlled chemically so also are the constituents just mentioned safeguarded in good fusion processes by similar metallurgical measures, such as suitable gas atmospheres, suitable fluxes or electrode coatings, and also in some cases by the chemical constituents of any added metal. Certain chemical reactions of carbon and manganese with oxygen, that tend to fritter away these particular constituents into the atmosphere or the slag, are taken account of by including surplus quantities of these elements in the slag or added metal; and the quantities of sulphur in fluxes, heating gases and electrode coatings are also carefully watched.

The process must, in short, obtain weld metal of correct chemical content.

DISTORTION, RESIDUAL STRESS AND CHILLING

All kinds of welding are accompanied by temperature conditions that tend to cause distortion, residual stresses and embrittlement due to chilling.

Local heating produces inequalities in temperature in and around the weld, and the resultant expansions and contractions are also unequal. Since these movements between adjacent parts exceed the maximum elastic stretch or compression of the metal, the metal is kneaded plastically by the progressive heating and cooling as the arc (or other welding medium) approaches and passes each part. The disposition in the finished weld of each particle of metal that has been heated to 200° C. or more has probably changed in its relation to neighbouring particles; and such changes have taken place in most of the metal in and around the weld. When the weld has cooled out it will be found that it has shortened the edges that have been joined, that there has been shrinkage across the weld seam, and probably that angular distortions have taken place. These effects, illustrated in a general way in Fig. 3, have to be taken account of in the technique of the particular welding process being used.

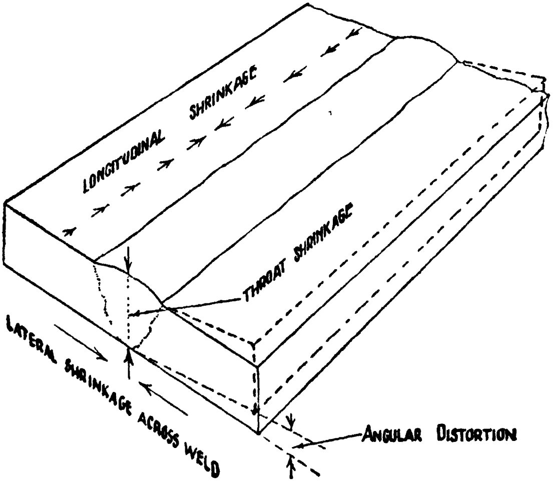


FIG. 3. GENERAL DISTORTION DIRECTIONS

Further, when metal is strained locally beyond its elastic limit so that local distortions or plastic movements take place as just described, it is found that the particles retain a seriously strained condition within the metal and exert stresses on each other, often of a high order close to the elastic limit of the material. This is merely because the metal retains practically all its elastic properties after plastic yield has ceased, the amount of plastic deformation at any affected part being negligibly small compared with the amount required to "work-harden" or otherwise affect its mechanical properties. These locked-up stresses in the heart of the material are called residual stresses and are an inevitable result of all methods of welding; they are, however, least damaging when the temperature and therefore the expansion differences at any instant are spread over a large area. This fundamental fact has to be allowed for in many fast and economical welding processes.

Finally, certain metals, notably the steels that are used to construct the vast majority of structures, i.e. mild steel and the high strength structural steels, may be "chilled" by rapid cooling after welding. Any structure of such steels that is cooled in still air after being heated (as a whole) to temperatures approaching the plastic welding temperature will be strong and ductile. Such a treatment is called normalizing and the metal, when cold, is in the "normalized" condition. When cooled more rapidly, the metal becomes stronger but less ductile, and as the rate of cooling is further increased the metal becomes still stronger but also increasingly brittle. Since welding with its localized heating often means that a small mass of red-hot metal is surrounded by a large mass of cold metal through which, owing to the high conductivity of the surrounding mass, heat is rapidly withdrawn, the rate of cooling is frequently so rapid as to cause such chilling and therefore embrittlement. A simple control of this danger is to make sure that the hot mass is not too small compared with the larger cold mass and that the proportion of hot to cold mass is increased as the normalized strength of the steel rises; because high strength steel embrittles more readily than mild steel. In a particular case in which cracking appears in a metallic arc weld connecting mild steel heavy parts the remedy is probably to increase the rate of heat input, thus overtaking the loss of heat and preventing chilling and embrittlement.

These thermal effects are thus all controllable by using a suitable welding practice, and the solution of these dangers is usually simple and easily obtained.

THE SUCCESS OF MODERN WELDING PROCESSES

In spite of the number and variety of welding problems, of which those just mentioned are probably the most fundamental, they have been successfully solved by modern processes. Gas envelopes, fluxes and slagging materials protect the metals from loss of desirable constituents or from the addition or increase of undesirable impurities; other metallurgical problems have been solved by the technique of welding practice; and distortion and the other thermal effects are also controlled by practice and design. Welds by modern processes are already so effective in many metals that failures are more to be wondered at than the most outstanding successes. This position has been reached because of the really scientific work of a vast number of research workers in an enormous number and variety of places, in many countries, in many kinds of laboratory and in many kinds of workshop. Finally, there has emerged a comparatively straightforward practical science, the most important precepts of which, from the point of view of the welder and the user of welding, can be easily understood and quickly assimilated. The imperative first requirement for good welding is that the problems involved should be always in mind and that the materials and methods peculiar to each process should be understood well enough to use them confidently in solving the problems just stated and in order to avoid others to which blind welding by uninformed craftsmen is prone.

ARC WELDING PROCESSES

There are three commonly used processes in which the electric arc is the source of heat.

Metallic arc.
Carbon arc.
Atomic hydrogen.

The first of these is by far the most widely used of all welding processes, and many welders and users of welding know little of the other processes. For this reason, and because its pre-eminence is justified by the economy and excellence of the results obtained, we shall examine metallic arc welding in more detail than either of the other arc welding processes mentioned above.

METALLIC ARC WELDING

The arc is struck between a metal rod called the electrode and the job, as illustrated in Fig. 4. Fig. 5 illustrates the welder's circuit. Fig. 6 illustrates the common welding tools. Two types of welding machine are illustrated in Figs. 7 and 9; these are the generator (D.C.) and transformer (A.C.) each for a single operator. Multi-operator machines of each type are illustrated in Figs. 8 and 10. Fig. 12 illustrates the joints used for metallic arc welding.

The arc is a little furnace of very high temperature, about 2700° C. at the negative terminal and 3700° C. at its positive terminal, and, it is believed, of even higher temperature in the arc itself. Even metal of high melting temperature, such as mild steel at about 1500° C., melts easily in this medium. The speed at which the metal is melted (say lb. per hour) depends on the rate at which electric power is supplied to the arc; a 10 kw. arc may be expected to melt twice as much metal as a 5 kw. arc in a given time.

Power = volts × amps., and these components of the power supplied must be correct within certain limits for good welding.

Actually the amount of work done by the arc is usually measured by the amperage. The voltage is usually controlled within narrow limits by fixing the suitable arc length for a given type of electrode and a given weld.

The arc length may be considered the measure of the voltage; a 35-volt arc may be twice as long as a 25-volt arc in a particular instance, because it takes so much more electro-motive force to carry the current across the larger gap. Thus, although not proportionally, E.M.F. and arc length increase or decrease one with the other.

The purpose behind the choice of a particular length of arc is always quite definite. If the electrode is a bare wire or a wire with a thin coating (giving little protection from air contamination) the arc is kept as short as possible in order to reduce the field of attack by oxygen; if the modern heavy-coated (or actively protective) electrode is used, a medium length of arc is generally chosen; sometimes, with modern electrodes a long arc is deliberately chosen for the sake of deep penetration.

Thus, the arc length or voltage is decided by factors other than the amount of heat to be delivered to the weld; and the amperage is the actual measure of heat from the welder's point of view. A welder seldom thinks of voltage (in number of volts) as a practical consideration, and if he wants more or less heat input, he increases or decreases the amperage output of his machine by a suitable control. It is usual therefore to evaluate the heat supplied to a given arc in amperes and

to measure the capacity of a welding machine in amperes.

From the operator's point of view, the arc is a small furnace the depth of which (the arc length or gap) is kept to a chosen dimension and the amount of heat in which can be varied by varying the amperage to suit the amount of work (welding) to be done.

The work done is the amount of metal melted. As indicated in Fig. 4 both electrode and parent metal are melted to mix together in the weld. The proportion of each, electrode and plate, in the weld depends to some extent on the *polarity* of the arc. If direct current is flowing across the arc from a welding generator the positive terminal of the arc is at a higher temperature than the negative terminal, so that whichever is the positive terminal, the electrode or the plate, will tend to melt more rapidly. Of course, there are other factors; for example, the plate, being of greater mass than the electrode, will dissipate (waste) more heat, and, on the other hand, the electrode may use up much of its share of the heat in melting the coating; a still further variation may be if the electrode coating supplies additional heat by combustion of some of its constituents. It is nevertheless safe to assume that if the electrode is positive the speed of adding metal from this source is greater than when the electrode is negative; and this is a major reason for using positive polarity for covered electrodes. It will be found that greater heat penetration into the parent metal is obtained when the plate is positive, for the same reason.

When alternating current is used, the polarity is constantly changing so that there is no choice in this case; both terminals of the arc are of the same temperature, except that the factors already mentioned (dissipation of heat, etc.) may alter the balance.

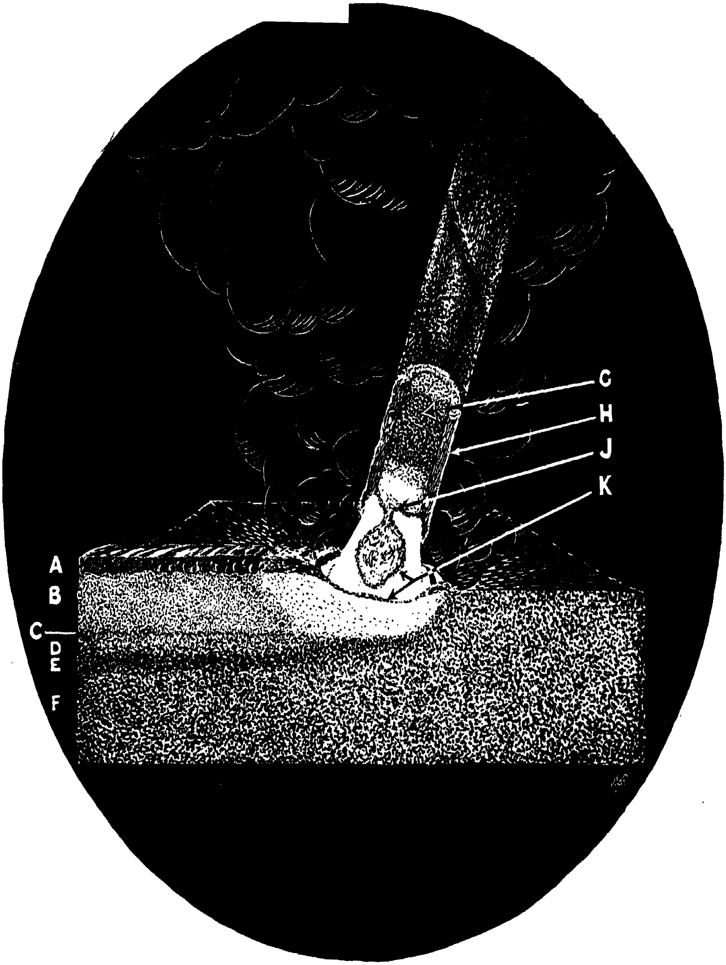


FIG. 4. THE METALLIC ARC IN WELDING

A. Protecting slag
B. Weld metal
C. Line of penetration
D. Recrystallized } Parent metal
E. Spheroidized } Parent metal
F. Pearlite ferrite } Parent metal

G. Electrode core
H. Electrode covering
J. Molten tip
K. Molten slag on drop and molten pool

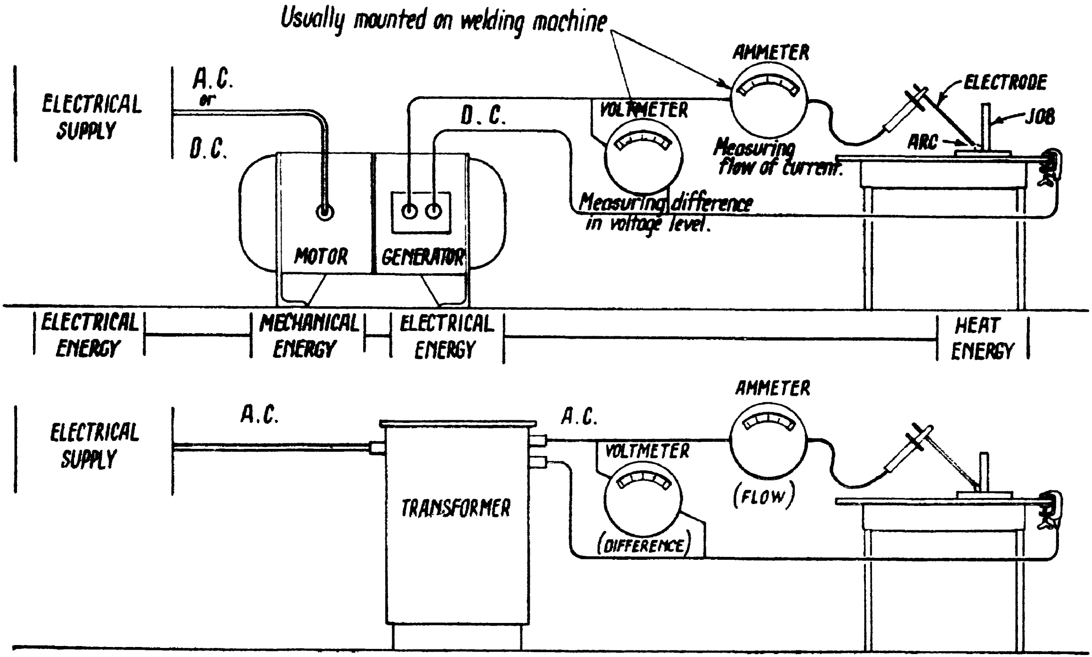


FIG. 5. ARC CIRCUIT

Thus, the length of arc (voltage), the current (amperage) and the polarity may all have a bearing on the behaviour of a particular welding arc.

The electrode illustrated in Fig. 4 is one of the heavy-coated type, giving both slag and gas shield protection. There are many other kinds, but the types that give this dual protection are usually definitely superior to other types; such electrodes frequently also make up losses, during welding, of carbon and manganese or other desirable constituents of the metal. Also there are few, if any, arc welding applications where such electrodes cannot be used economically. (The appearance of the electrode is no indication of its value in this respect; dual purpose coatings are often merely extruded pastes.)

As already indicated, the type of electrode largely controls the permissible length of the arc and the arc may be lengthened in any particular instance only to that limit at which oxygen and nitrogen are still excluded successfully from the weld. The importance of the job is, of course, a factor; for example from this point of view a pressure vessel is more important than a building structure, and a rapidly and heavily vibrating machine part more important than the bed plate of a slow-moving hydraulic ram. The more exacting the service demanded of the welded job the more important is it that oxygen and nitrogen shall be excluded from the weld and the chemical content of the weld metal be secured by the choice of a first-class electrode and by keeping the arc length within permissible limits.

There is a large variety of electrodes being sold at present even for the single purpose of welding mild steel. The makers have put much thought and work into the development of these electrodes and the quality is therefore already of a high average. The variety will probably decrease rather than increase because advancing science tends to simplification. It is also being discovered that it is no longer necessary to use an inferior electrode to weld vertically so that decreasing variety may be expected also on this account. It should be emphasized that it is quite practical and economical to use first-class electrodes for all welds. The only qualifications required of a first-class electrode in addition to those already mentioned are that it should carry relatively large currents (for the sake of quality as well as speed) and that it should deposit smoothly so long as the welder holds a steady arc.

So far as electrode tests are concerned, the weld metal should prove as strong, as ductile, and as capable of impact test as the minimum values required of the parent metal. (There are no exceptions to this rule in structural steels.) In other words, the aim in all welds is to obtain mechanical homogeneity with the parent metal, or to reach as nearly as possible to this ideal.

✓WELDERS' TOOLS

These require little special description. Fig. 6 shows, of course, only one design of each, and there are many variations. The helmet, gloves and apron protect the welder's body from the heat and spattering metal and his skin from the ultra-violet and infra-red rays of the arc. Special protection is required for his eyes and standard shades of green and amber glass are obtainable; the quality of these glasses is such that the ultra-violet and infra-red rays cannot penetrate them in harmful quantity, yet the eye can see clearly through them the progress of the welding; different welders require different shade densities. These are the general characteristics and requirements in the welders' tools.

✓ WELDING MACHINES

The functions of welding machines are as follows—

1. Current must be supplied in suitable values for a variety of welds, i.e. current must be variable by small increments of value over a wide total range.

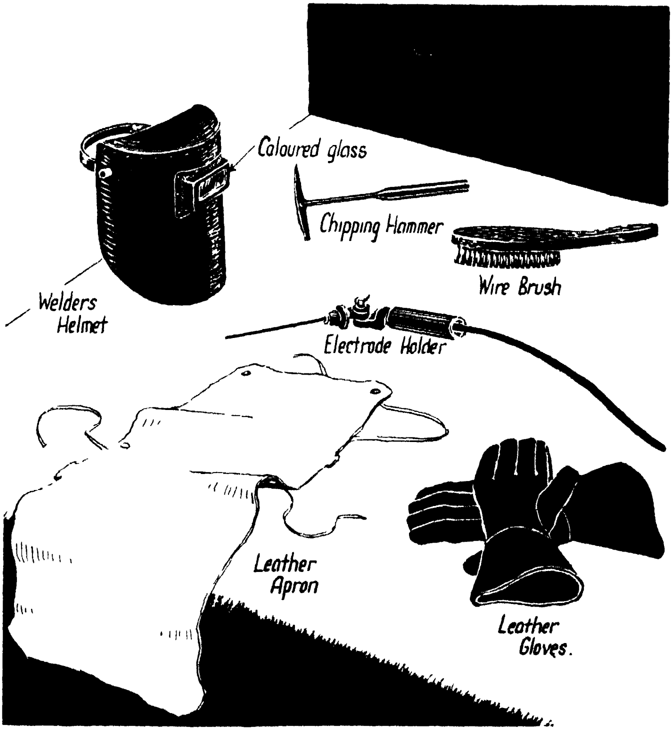


Fig. 6. Common Welding Tools

2. The working voltage of the supply must be sufficient to maintain the arc across the arc gap with

an ample margin for voltage losses in the welder's circuit.

3. For "striking" the arc, the "potential difference" (voltage) between the electrode tip and the job must be high enough (about 2½ times the arc voltage and often twice the working voltage).

4. Variations in current while welding must be as small as possible, even when voltage varies largely; involuntary (by the operator) variations in the arc length, and therefore the arc voltage, must not cause inversely proportional variations in the current; (as power = volts × amps., power must be automatically variable).

5. If a large globule touches the job before it leaves the electrode, short circuit takes place; the arc is extinguished and must be "re-struck." The recovery of the arc and of the current and voltage values of the arc after each short circuit must be virtually instantaneous.

The most commonly used machines are welding generators for direct current, and welding transformers for alternating current.

Consider first the welding generator. It may be driven by any mechanical source of power (e.g. an electric motor or a petrol engine) by means of which the armature of the generator is revolved at a given speed. As the armature windings pass through the fields of the generator poles, Fig. 7, E.M.F. and current are induced in the armature windings, the voltage and amperage depending on the strength of the fields and the rate of the armature revolutions. Presuming the armature to revolve at constant speed, all the variations in current and voltage values must apparently be by altering the fields; in general terms this is true.

Adjustment of the regulator for alteration to current output adjusts the strength of the field, probably by altering a resistance in the circuit of the field coils, or by altering the number of field coils, or by alterations to the gap between a pole piece and the armature. In one representative design of machine, the alteration to the number of field coils is used to make major alterations to the field and minor alterations are made by means of a resistance in the main exciting circuit. Fig. 7 shows a typical design with two separate sets of field coils, one of which, roughly speaking, passes exciting current during idling (no arc) periods and the other passes welding current during welding periods. The fields from the two currents are opposing one

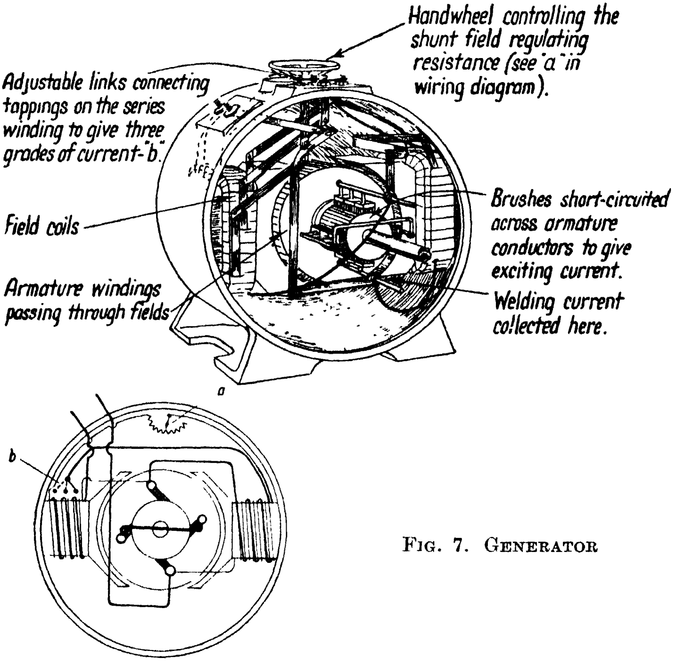

Handwheel controlling the shunt field regulating resistance (see "a" in wiring diagram).
Adjustable links connecting tappings on the series winding to give three grades of current-"b".
Field coils
Brushes short-circuited across armature conductors to give exciting current.
Armature windings passing through fields
Welding current collected here.
a
b

FIG. 7. GENERATOR

another (thus obtaining the drooping characteristic) and it is an important part of the design to arrange these or such coils so that under all running and welding conditions the fields are of the required strength.

From the welder's point of view the requisite properties are obtained in the machine if by each setting a known and suitable open circuit voltage, working voltage and current arc obtained. (The working voltage includes the arc voltage and the loss in cables, etc., in the welder's circuit.)

The success of a welding generator is dependent on how well the designer has solved the problems involved in fulfilling the functions of the machine as stated above; a good practical test of a generator is to run one weld with bare wire and a second weld with a heavily-coated, gas-producing electrode, and if both give good depositing behaviour (each in its kind) the machine is satisfactory. Machine designs are, of course, of great variety, and the foregoing does meagre justice to the ingenuity that has been shown by designers in bringing welding generators to their present-day quality. These are generally called "drooping characteristic" machines (drooping from "striking" to "working" voltage).

Multi-operator welding generators cannot be of drooping characteristic design since a single generator is supplying current to a number of welding circuits in which the striking of all arcs simultaneously is practically impossible. In this case the generator must supply current at striking voltage, and a variable resistance is placed in each welder's circuit. The variable resistance serves the double purpose of regulating the power in the particular circuit and, in conjunction with the arc gap held by the operator, of supplying the current at the requisite voltage value. Unless these machines are overloaded seriously the open circuit or striking voltage, which in this case is also the working voltage in the welding circuit (including the regulator), need not be so high as the open circuit voltage in the single operator machine; operating at only 45 volts, arcs may be struck that might otherwise require at least 70 volts. Commonly, however, these are 60–70 volt machines. The illustration (Fig. 8) shows the circuits; the generator is a simple level characteristic machine.

Transformers are less complex in their construction than generators and contain no constantly moving parts. Roughly speaking, a welding transformer consists of two coils on a common core, i.e. with a common field, the primary coil collecting alternating current at mains voltage and the secondary coil delivering induced alternating current at welding voltage.

Generally in Britain electricity supply is 50-cycle, 3-phase, 440 volts A.C., and the voltage across two phases may be about 250 volts. The function of the transformer is, firstly, to transform the voltage to a level suitable for striking the arc. The secondary coil contains, therefore, only about one-third of the number of the coils in the primary; and the induced voltage is thus about one-third of the primary voltage (say about 80/90 volts). The E.M.F. and current delivered to the welding circuit are obtained from the secondary coil and may be altered to some extent by plugging into suitable portions of the secondary coil or by moving it out of or into the field, so that the secondary voltage available for driving current through the welding circuit is altered by altering the number of secondary turns in the common field.

The reduction to welding voltage after "striking" and most of the regulation of current are, however, usually obtained by inserting a choking coil into the

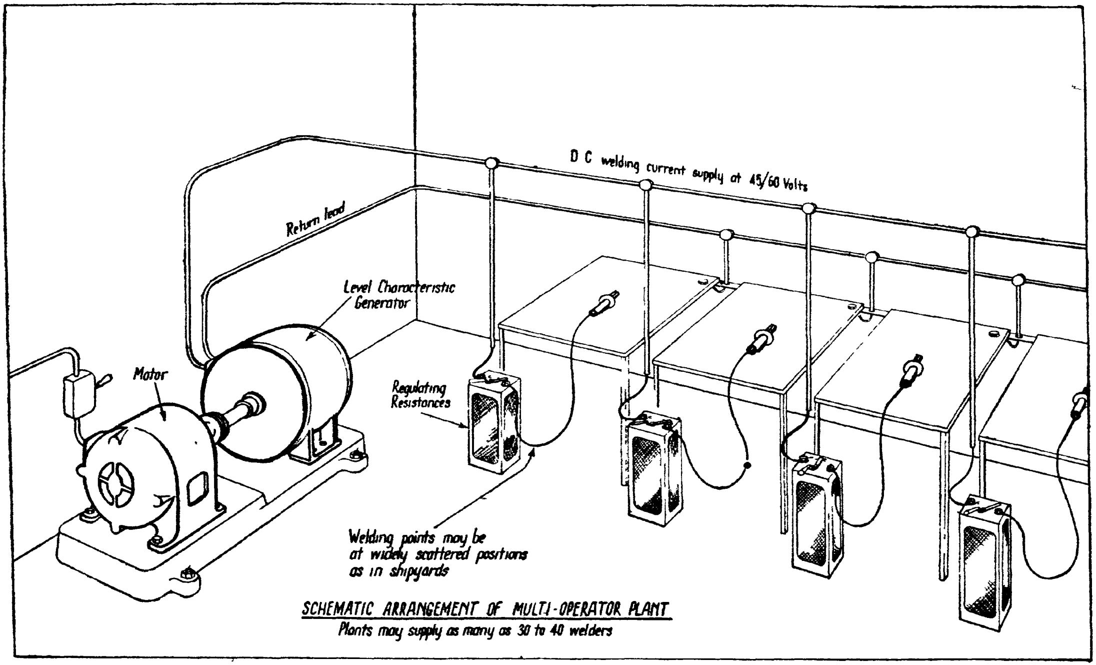

D C welding current supply at 45/60 Volts
Return lead
Level Characteristic Generator
Motor
Regulating Resistances
Welding points may be at widely scattered positions as in shipyards
SCHEMATIC ARRANGEMENT OF MULTI-OPERATOR PLANT
Plants may supply as many as 30 to 40 welders

FIG. 8. MULTI-OPERATOR GENERATOR

welder's circuit. This is a single coil the self-induction of which can be varied by moving the core piece into and out of the field, so that the varying field displaces a varying amount of current and E.M.F. out of phase. The out-of-phase portions of the current and E.M.F. reduce the effective output of the transformer and choking coil to the current and E.M.F. required to maintain the arc for the particular weld then being laid, because this out-of-phase portion of the output is wattless, i.e. it develops no power.

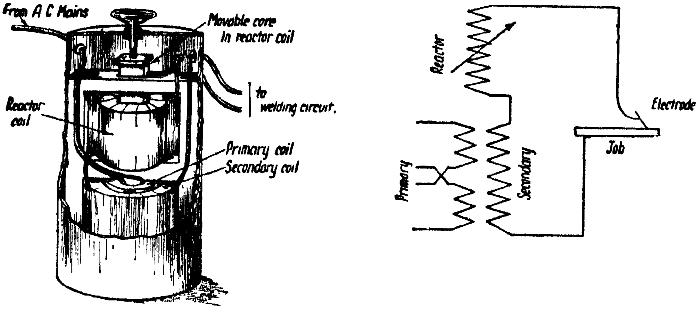


FIG. 9. TRANSFORMER

Multi-operator transformers are usually three-phase machines, the individual welder's circuits being collected from each phase in turn. To illustrate some typical machines, the arrangement of several transformers is illustrated diagrammatically in Fig. 10.

In installing a number of single welding transformers, the phases are taken in turn, so that if the conductors of the three-phase current are *A*, *B* and *C*, *A* and *B*, then *B* and *C*, and finally *C* and *A* are crossed by each primary coil in turn; this arrangement is often considered of practical importance in order to try to balance the load over the three phases of the supply.

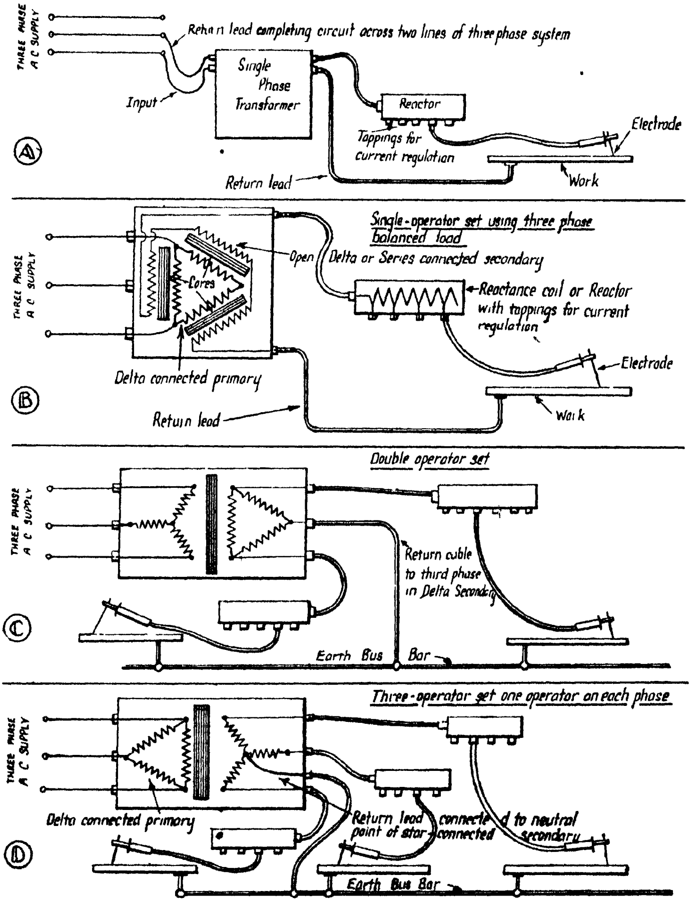

THREE PHASE A C SUPPLY
Return lead completing circuit across two lines of three phase system
Input
Single Phase Transformer
Reactor
Tappings for current regulation
Electrode
Work
Return lead
A
Single-operator set using three phase balanced load
Open
Delta or Series connected secondary
Cores
Reactance coil or Reactor with tappings for current regulation
Electrode
Delta connected primary
Work
Return lead
B
Double operator set
Return cable to third phase in Delta Secondary
Earth Bus Bar
C
Three-operator set one operator on each phase
Delta connected primary
Return lead connected to neutral point of star-connected secondary
Earth Bus Bar
D

FIG. 10. MULTI-OPERATOR TRANSFORMER

At the same time, the fact that no three operators can be depended upon to keep perfectly in step, even when their jobs are perfectly similar, means that in spite of this precaution the load from groups of transformers is never really completely balanced. In spite of this the supply companies make little or no trouble about the use of the popular welding transformer.

The four types of machine so far described are illustrated typically in Figs. 7, 8, 9 and 10. There are, of course, several makers of each type of machine and the modern standard of construction and design is high.

The use of each type depends on circumstances. The capital cost of transformers is less than that of generators of equivalent power, but it is usually advantageous to have at least one or two generators in a welding plant for the welding of certain metals (see later). Also the power cost with a modern drooping characteristic generator may be slightly lower than with a transformer. Finally, for large plants on exposed sites (such as shipbuilding berths) it may be judged best in the interests of safety to use D.C. and considered economical to use large group multi-operator generator sets.

The capital cost of welding machines and the cost of the current they use is not entirely negligible, and they should be given careful consideration in laying out new plant. (At the same time the costs of labour, electrodes and upkeep of cables and welder's equipment offer much more scope for workshop economy.) The first cost and upkeep of the welding machines described above will appear to favour the single-operator drooping-characteristic generator and the transformer rather than the inefficient level characteristic multi-operator generator. This is probably usually true, especially because of the inconvenience caused by a breakdown of the larger unit and the facility with which the smaller units can be moved from point to point. On the other hand, the multi-operator generator can be employed very economically on occasion, provided the following facts are borne in mind.

1. If the maximum current likely to be required at each welding point is, say, 300 amps., but the average current over all the welding points at any one time (even if all were working) is likely to be 200 amps., the total current required from the generator is 200 (not 300) times the number of welders.

2. Each plant has its own welding time factor, which is the proportion of total working hours spent on actual welding. Allowing for cleaning welds, changing electrodes, adjusting the job and many other smaller losses of time, an economical welding time factor in better-than-average conditions on large structures is 33⅓ per cent. The effect of this is that there is seldom any one instant in which more than one-half of the total number of welders is at work.

3. It is probable that the generator is capable of a considerable overload, i.e. above its continuous-rating output.

In order to recover some of the higher cost of current from multi-operator welding generators, advantage may be taken of the three factors just mentioned; when it will be found that the capital cost of the plant will become relatively small. The advice of the makers should be taken in deciding the size of a machine, but as a rough guide this formula may be used—

$$I_R = \tfrac{3}{2}(N_W I_A F_S)$$

Where I_R = total current required.

N_W = number of welding points.

I_A = average current per welder at full overall load.

F_S = shop welding time factor.

It is, of course, a serious mistake to underestimate the duty required from welding machines because the tendency of modern welding is towards higher currents, for the sake not only of economy but also of quality. I_A must, therefore, not be underestimated. Also, the voltage should be decided with two important considerations in mind.

Even in those large machines, and even when the reserve current is large, the striking voltage should be much higher, usually at least 50 per cent greater, than the maximum arc voltage.

The manufacturer of the machine should always be fully informed as to the number of welders, size of welds to be made, the electrodes it is proposed to use, and of a preference (if any) for any special arc length, particularly if long arcs (and higher voltages) are specially favoured.

DIRECT AND ALTERNATING CURRENT

Much controversy has arisen periodically on the merits and demerits of each type of current. At the outset it can be definitely stated that the choice of either is never a sufficient excuse for a bad weld. Good welds can be made by both D.C. and A.C. arcs in most welding conditions, provided good sound covered electrodes are being used. No tests (given suitable metal, of course) have ever proved conclusively that either type of current was definitely inferior to the other, except in one respect, and this must always be borne in mind and taken account of in practice by the welder.

Every conductor is surrounded (so long as current is flowing) by a magnetic field, the strength of which increases or decreases with the current values. The welder's circuit including the job is essentially made up of a series of such conductors. Also, the electric arc is susceptible to magnetic influences and appears to become increasingly susceptible as the current value rises. If the arc were of steady current and voltage values the magnetic effect might be to deflect the arc constantly into or away from the nearest conduction path (other than its own shortest axis); but the arc (particularly the metallic arc) is very unstable, and fluctuations in the current values sometimes cause sudden and violent changes of direction in the arc. Sometimes the conduction paths (particularly those through the mass of the job) are difficult to trace, and correction on theoretical grounds is therefore difficult. There is, however, a best position for the "earth" or "ground" connection, by means of which the wanderings of an arc may be reduced to the minimum; this is usually best found by trial and error, and the position may have to be changed for different welds or even as the arc proceeds along any particular weld.

The magnetic disturbance of the arc is completely absent in alternating current, and when large current values are the rule, A.C. may be found to be advantageous; sometimes, however, a change of electrode type may eliminate most of this disturbing D.C. effect.

It should be repeated, however, that bad workmanship is never actually due to the use of D.C., although any welder who persists in using a violently wandering arc without making any of the corrections suggested above will, of course, make a bad weld.

A certain danger exists with alternating current, but it can be easily over-emphasized. The open circuit voltage should not exceed some safe figure (120 volts is mentioned in the Home Office Memorandum, extracts from which will be found in the Appendix to this section). If the voltage of any A.C. circuit is 90 volts, the instantaneous maximum value occurring twice in each cycle is 126 volts; this maximum probably meets the spirit of the Home Office Memorandum. But certain welding transformers have higher open circuit voltages, actually up to 110 volts. Even then, under shop conditions, the danger is slight, given good sense and strict adherence to the other relevant recommendations in the Memorandum, particularly as regards earthing and isolation of the primary from the secondary current.

So far we have considered only the most extensively used types of machines, generators and transformers. When A.C. supply is available, either may be used, a transformer or a motor generator; but if D.C. is the source of power there is no choice, the motor generator being the only possible type. When there is no electric supply available, a generator type of machine is driven by a petrol or Diesel oil engine.

Further types of welding machines, both usually applied specially to welding thin sheets, are the mercury arc and plate type rectifiers. In both cases rectification of the alternating current is obtained, broadly speaking, by passing the current across a medium which permits passage in one direction only. The current is thus rectified to D.C. High-frequency generators can also be obtained.

WELDING CABLES

These are a very important factor in the cost and efficiency of welding plant. The cost of the cables may exceed the cost of machines by many times and the voltage drop in excessively long cables may cause both bad and costly welding.

It is important that the user should include the cost of cables in estimating the total capital cost in each lay-out, and that these cables should be made large enough in section in proportion to their length to carry the maximum current without serious voltage drop due to the resistance of the cables.

The makers of cables supply tables of current carrying capacity and voltage drop for the guidance of users.

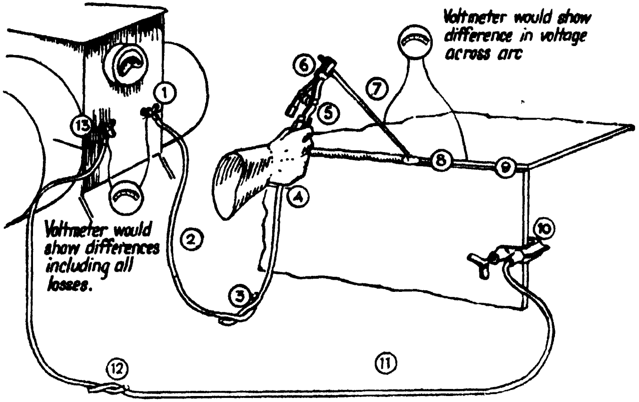

Voltmeter would show difference in voltage across arc
Voltmeter would show differences including all losses.
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬

FIG. 11. FAULTS IN CIRCUIT

1. Fault at connection of lead to machine.
2. Lead too small and heating up.
3. Faults in the lead: Breaks or partial breaks.
4. Faulty connection of lead to holder.
5. Faults in the holder.
6. Faulty contact between holder and electrode.
7. Heating-up of electrode (inevitable to some extent).
8. The arc (depending on its height).
9. Faulty contact between parts in a job.
10. Faulty connection of return to job.
11. Return too small and heating up.
12. Faults in the return: Breaks or partial breaks.
13. Faulty contact between return and machine.

Note. The circuit is most efficient when the faults noted above are reduced to the minimum, i.e. when item 8 represents the largest possible percentage of the whole voltage expenditure.

FAULTS IN THE WELDER'S CIRCUIT

The faults commonly met are illustrated in Fig. 11. These are the faults over which the welder has personal control. They are of two kinds, firstly interruptions that waste current and tend to break the arc, and secondly short circuits that not only waste current but also endanger the lives of other operators. The interruptions are probably quite sufficiently explained pictorially by the sketch; a typical example of blameworthy short-circuiting is when a welder earths his current through a building structure on which other operators may be working in precarious positions.

The golden rule about the circuit is that the welding current should pass through a continuous and, as far as possible, completely insulated path, from the welding machine through the welder's cable to the arc, and return by insulated paths, through the return cable, to the machine; there should be no live and uninsulated parts of the cables and no deviations of the current into surrounding structures.

Welding current is of course of very low voltage and is unlikely to do serious damage by shock, but if a precariously balanced erector or sheeter suddenly touches live metal, the shock may be sufficient to make him lose his balance and sustain serious injury, or worse.

FACTORS IN PRACTICE

The common types of weld by this process are illustrated in Fig. 12. The illustration is self-explanatory; it will be noted, however, that most of the welds are of the filled-in type, i.e., the weld is built into a vee or a corner with only slight penetration into the parent metal. A common error should be disposed of at this stage. It is still quite commonly believed that the weld metal is fundamentally inferior to the parent metal, but this need not and should not be the case, especially when welding together pieces of the structural steels. If the electrodes are carefully chosen in order to secure the correct chemical contents and balance in the weld and if the welding procedure ensures that the metal is not chilled, the weld metal will be steel of a suitable composition and condition and will have the qualities of that metal. The weld is not a foreign metal, e.g. a

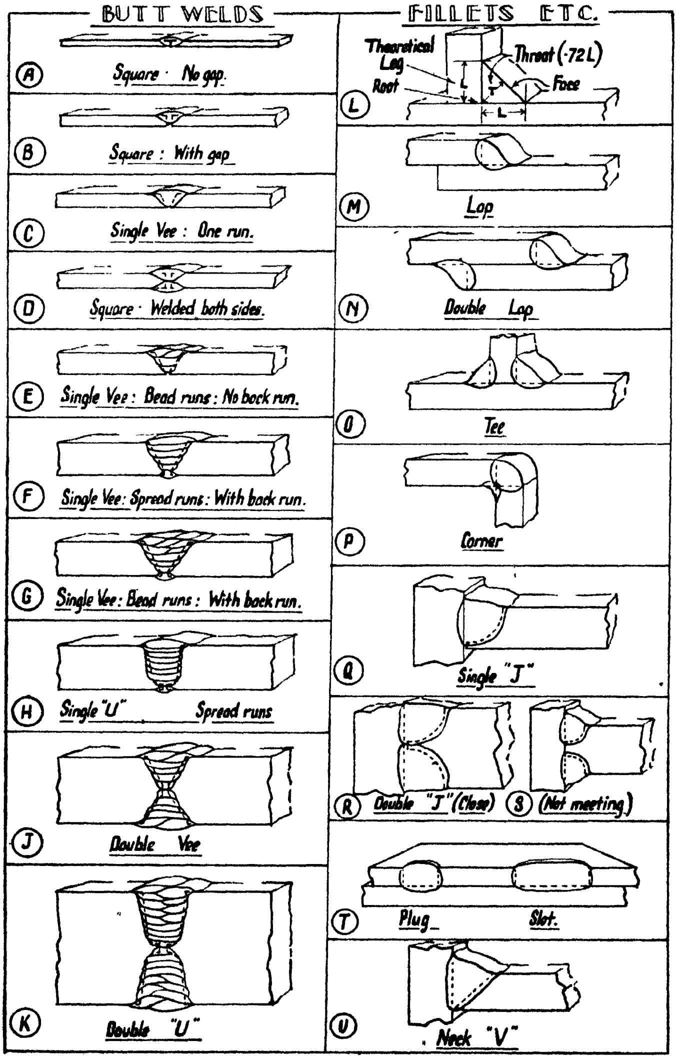
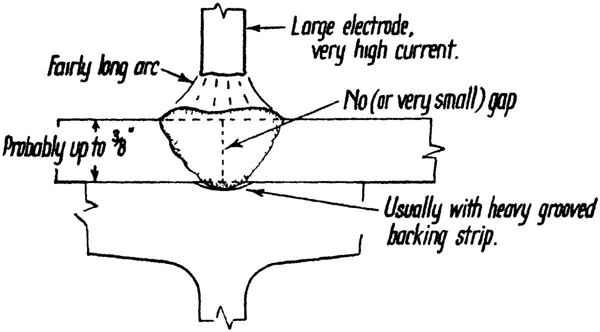


Fig. 12. Arc Joints

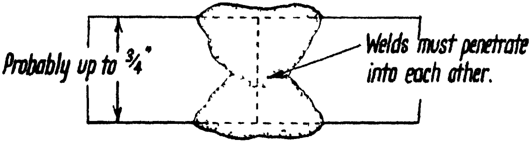
solder; on the contrary its strength can be calculated almost as if it were an original part of the parent metal.

The strength value of the weld is therefore measurable by its shape and position relative to the stresses it must support. For this reason, the butt weld is the most satisfactory of all welds, because it is a true continuation of the original metal. Fillet welds, on the other hand, are placed at corners where two pieces meet (probably at right angles) in such a way that the structural shape changes the stress direction abruptly. In this case the weld is supporting concentrations of stress that are sometimes difficult to estimate. The importance of the form of the weld is therefore great, not only to the designer but also to the welder. Sharp corners, undercut and lumpy, uneven surfaces should be avoided and the ends of welds should be smoothed off where possible.

Further, while mild steel weld metal should be of full plate strength, porosity and pockets of slag may easily reduce considerably the strength of good metal. The welder's knowledge of practice must therefore be very sound. Although the straight butt weld (Fig. 12A) is possible in only a limited number of applications, it is so economical and effective that it is worthy of special mention. This type of weld depends almost entirely for its success on complete penetration; and two factors in penetration already mentioned are voltage and polarity. It will be found, however, in practice that the type of electrode is an important factor; some electrodes penetrate more fiercely than others, and the degree can be found only by test. It may also be found that penetration is actually deeper with A.C. than with either of the D.C. polarities when certain electrodes are used. So far as voltage or arc length is concerned, the arc can be drawn only to the length or gap that can be bridged by the working voltage of the generator or transformer, and it is easy to make a mistake in giving this a value in volts, unless full account is taken of the losses in the circuit, or the voltmeter is bridged across the electrode and the job close to the arc (which is impracticable in continuous working conditions). Also, the arc should not be drawn to such a length that the atmospheric attack becomes dangerous. Long arcs should, therefore, be used with great care; their advantage may easily be overestimated.



STRAIGHT BUTT (OR SQUARE EDGE) WELDS FROM ONE SIDE ONLY.



WELDS FROM BOTH SIDES - NO BACKING STRIP REQUIRED.

FIG. 12A

The greatest factor in penetration is actually the current value. For deep penetration the current must be high, keeping in mind—

(1) that high current means high rate of heat input;

(2) that rapid heat input distributes the residual stresses over a large area so that individual particles of the metal cannot be violently strained; and

(3) that the metal is also prevented from cooling too rapidly by large quantities of new heat overtaking the heat conduction of the surrounding metal.

It will be apparent that the quality of the weld is improved in many ways by the use of high current. Also labour and electrode costs are reduced greatly by the high current method. For all of these reasons the amperage should be high in this and other welds; in straight butt welds this high current value is essential because ample penetration must be obtained. Currents as high as 600–800 amps. have been used on ½ in. to ¾ in. plates in certain extreme cases.

It is necessary to use a grooved backing strip if the straight butt weld is a single run from one side, but a run from each side is usually advisable.

Deep penetration into the root of tee fillet welds is sometimes considered good; it is doubtful if this is frequently necessary, but, as already mentioned, the form of the weld and the paths of stress distribution are the important considerations.

WELDING POSITIONS

The welds just described can be laid only in the "downhand" positions. Other common welding positions are illustrated in Fig. 13. Methods of laying "beads" and "layers" in the more conventional "filled-in" types of butt and fillet welds are illustrated in Figs. 14 to 19. The deposition method varies greatly with the "position," as will be apparent.

The current value used with a given electrode varies greatly with the welding position. A rough idea of the current value used with several diameters of electrode is given in the table on p. 272. The tendency

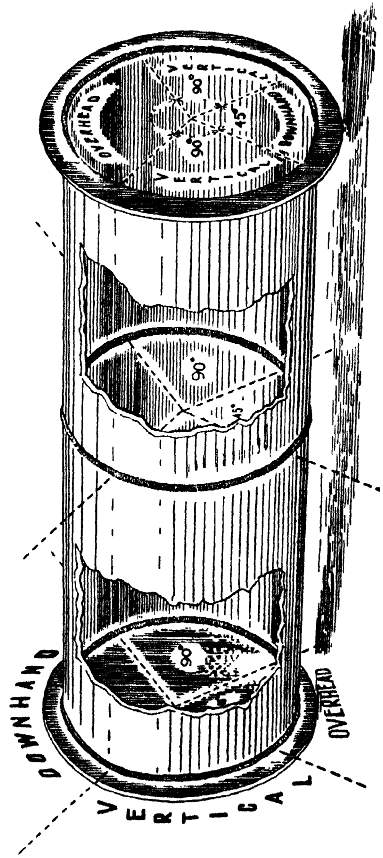


FIG. 13. WELDING POSITIONS

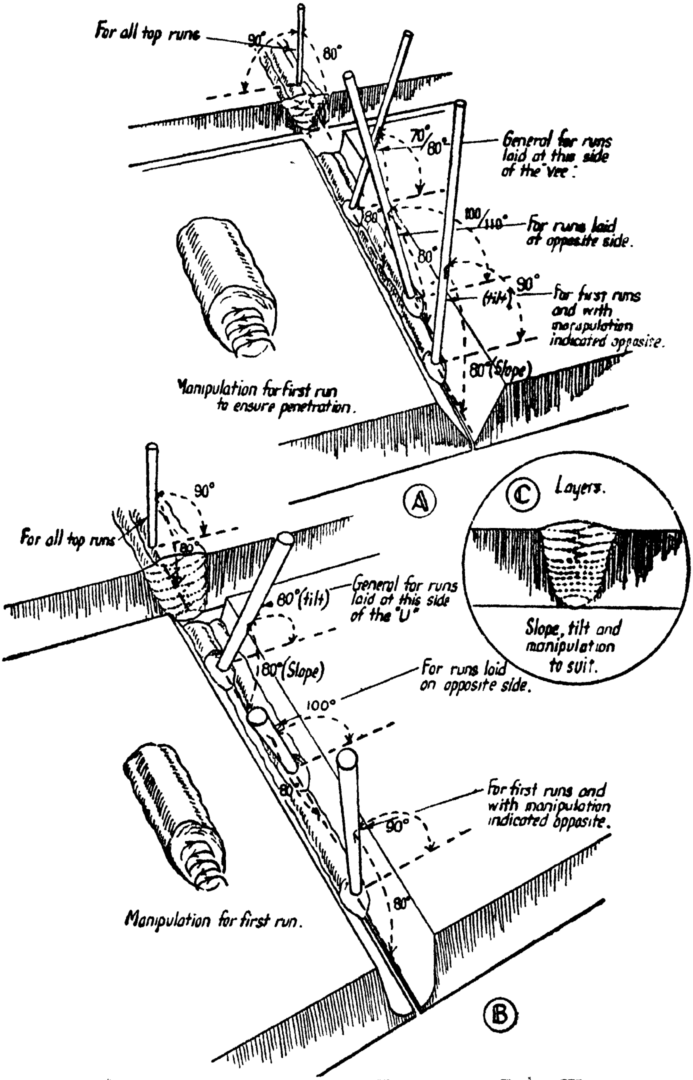

For all top runs
90°
80°
70°/80°
General for runs laid at this side of the "vee".
80°
100/110°
For runs laid at opposite side.
80°
90°
(tilt)
For first runs and with manipulation indicated opposite.
80° (Slope)
Manipulation for first run to ensure penetration.
Ⓐ
For all top runs
90°
80°
80° (tilt)
General for runs laid at this side of the "U"
80° (Slope)
For runs laid on opposite side.
100°
80°
For first runs and with manipulation indicated opposite.
90°
80°
Manipulation for first run.
Ⓑ
Ⓒ Layers.
Slope, tilt and manipulation to suit.

Fig. 14. Typical Procedures (Horizontal Butt Welds)

should always be to find methods of using the higher currents in the ranges given, for all of the reasons already stated.

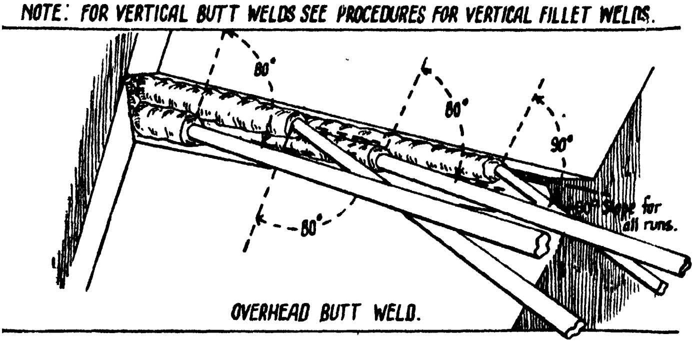

NOTE: FOR VERTICAL BUTT WELDS SEE PROCEDURES FOR VERTICAL FILLET WELDS.
80°
80°
90°
80°
Slope for all runs.
OVERHEAD BUTT WELD.

FIG. 15. TYPICAL PROCEDURES (BUTT WELDS OTHER THAN ON THE FLAT)

WELDING CURRENTS

(HEAVY DUTY ELECTRODES)

Electrode Dia.	Downhand	Vertical	Overhead
	Amps.	Amps.	Amps.
10 gauge . .	90 to 130	80 to 110	80 to 90
8 gauge . .	120 to 160	110 to 140	100 to 130
6 gauge . .	180 to 250	140 to 220	
¼ in. gauge . .	240 to 450	200 to 300	
$\frac{5}{16}$ in. gauge . .	300 to 500		
⅜ in. gauge . .	350 to 600		

There are certain materials, however, for example cast iron and 12 to 14 manganese and other austenitic steels, in which slow cooling is not an advantage. Such

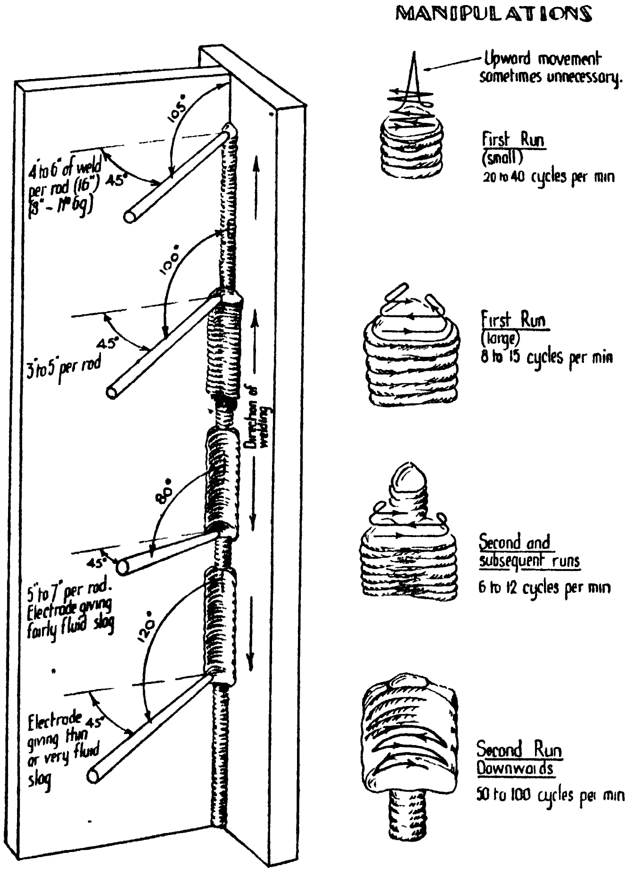


FIG. 16. TYPICAL PROCEDURE (VERTICAL FILLET)

exceptions are described later, but slow cooling is advantageous in probably 95 per cent of all welded work.

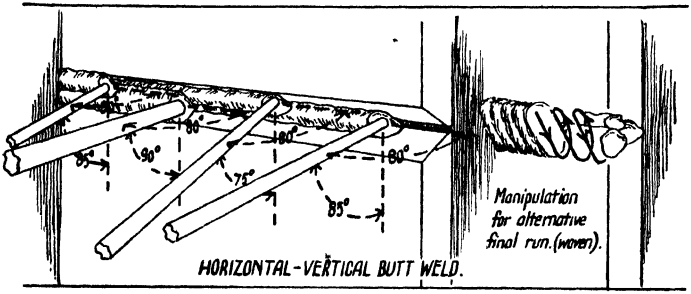

85°
90°
80°
80°
75°
80°
85°
HORIZONTAL-VERTICAL BUTT WELD.
Manipulation for alternative final run.(woven).

FIG. 17. TYPICAL PROCEDURE (HORIZONTAL-VERTICAL BUTT WELD)

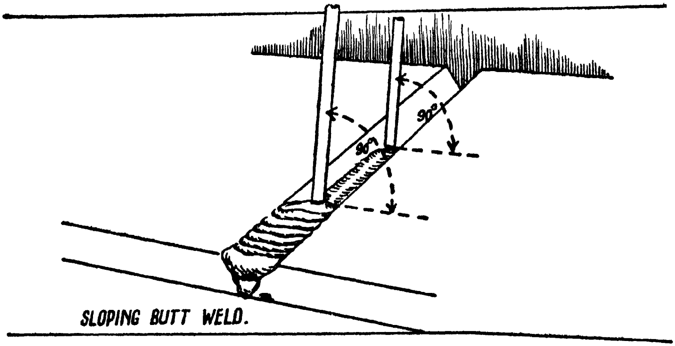


FIG. 18. TYPICAL PROCEDURE (SLOPING BUTT WELD)

SCOPE OF THE PROCESS

The metals and alloys to which the metallic arc process can be applied are discussed briefly on pp. 323–335, in some general notes on the welding of various

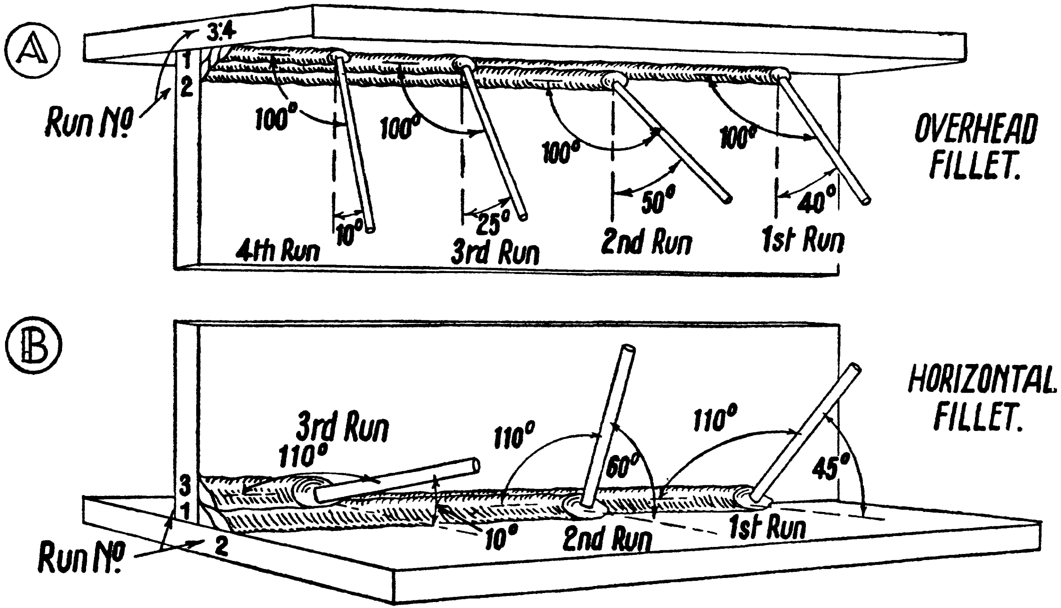


FIG. 19. TYPICAL PROCEDURES (FILLETS)

metals. For the present let us consider only the scope of the process in terms of the variety of types and designs of structural units that are commonly met. Pressure vessels, boiler structures, ships, bridges, buildings, many large and small machines, gas holders, all kinds of tanks and plate work: these are only a few of its applications. The process has been very severely tested in service as well as in laboratories. The laboratory tests for pressure vessel welding illustrated in Fig. 20 are typical. These are made on specimens welded with the vessel and by the same procedures. They are supplemented in important pressure vessel welding by a search of the whole of the main butt weld seams by *X*-ray, so that any major faults or inclusions in the seams can be removed by cutting out and re-welding.

Arc welding of pressure vessels is scrutinized much more carefully than the welding of any other class of work and is therefore undoubtedly comparatively much more expensive, but all the additional cost is accounted for by the inspection. Welding as such owes its excellence entirely to the routine followed, and strict adherence to and control of welding routine is profitable in all kinds of welding. In all kinds of jobs an assurance that the operators will consistently produce a given result enables the designer to use every part of the parent and weld metal to the best advantage. Procedures chosen and the results they will obtain should be understood thoroughly by designers, shop management and welders; this is the only safe rule for any kind of welded work (by any welding process). This rule also keeps down costs.

Four typical applications of the process are illustrated in Figs. 21 to 29.

(1) Figs. 21 and 21A show a design form of pressure vessel which had developed over decades of practical

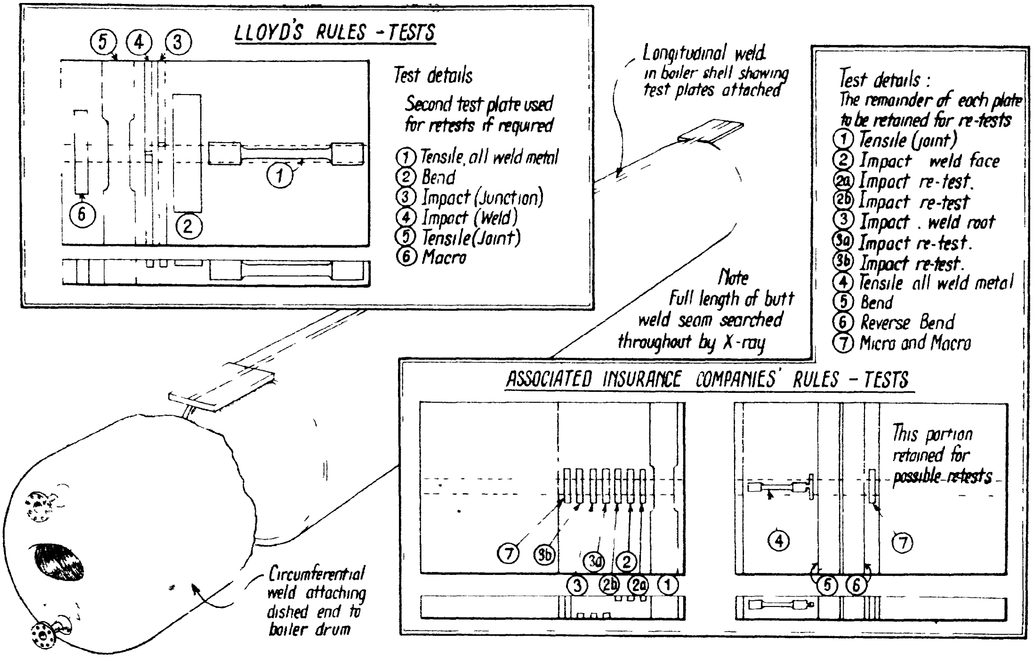

LLOYD'S RULES - TESTS
⑤ ④ ③
① ② ⑥
Test details
Second test plate used for retests if required
① Tensile, all weld metal
② Bend
③ Impact (Junction)
④ Impact (Weld)
⑤ Tensile (Joint)
⑥ Macro
Longitudinal weld in boiler shell showing test plates attached
Test details :
The remainder of each plate to be retained for re-tests
① Tensile (joint)
② Impact weld face
2a Impact re-test.
2b Impact re-test
③ Impact . weld root
3a Impact re-test.
3b Impact re-test.
④ Tensile all weld metal
⑤ Bend
⑥ Reverse Bend
⑦ Micro and Macro
Note
Full length of butt weld seam searched throughout by X-ray
ASSOCIATED INSURANCE COMPANIES' RULES - TESTS
⑦ 3b 3a ②
③ 2b 2a ①
This portion retained for possible retests
④ ⑦
⑤ ⑥
Circumferential weld attaching dished end to boiler drum

FIG. 20. PRESSURE VESSELS (FIRST CLASS) INSPECTION DETAILS

experience in the making of pressure vessels of riveted design. By using welding with the same general form, weakening of the plate at the joint by rivet holes is eliminated, so that the plates can be made much thinner and the whole unit much lighter. Caulking, not only when the vessel is first made but also at periods during its service, is eliminated. Abruptly diverging lines of stress, inevitable in a riveted joint, are entirely absent in the butt-welded pressure vessel. Welded vessels can be manufactured for much higher pressures than can riveted vessels. As already shown, tests of the joint for strength, ductility, density of weld, impact value and heat treated condition are all possible and are actually conventionally carried out; whereas riveted joints for the same duty are to this day taken largely on trust by the inspection bodies.

In spite of the apparent disadvantage of being treated with so much suspicion, the process has actually contributed quite considerably to the expansion of the pressure vessel field of work. Large vessels for containing and processing the refining of oil, such as cracking vessels, could scarcely be expected to operate nearly so successfully if riveted, as the inevitable leakage would be costly and dangerous; while those very high pressure steam vessels in which large temperature and pressure changes occur with every start up and stop down of a boiler unit must be welded or formed by forging, the latter being a costly alternative. The truth is that the severity of the tests of pressure part welds is building a new tradition of special and peculiar confidence in the units so manufactured.

(2) Large bed plates may be formed of very heavy castings, bolted together. If the shape of the castings is simple, so that, during casting, the molten metal flows easily into every corner of the mould and packs even the fillets with solid metal, and if shrinkage takes place

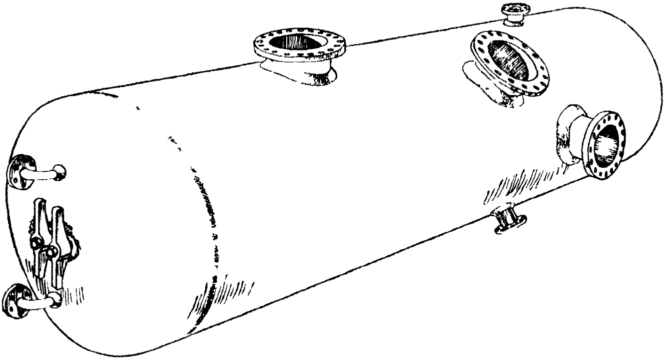


Fig. 21. Steam Receiver—Welded Construction

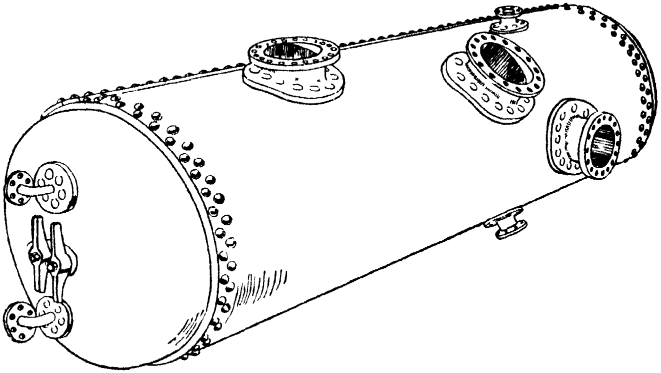


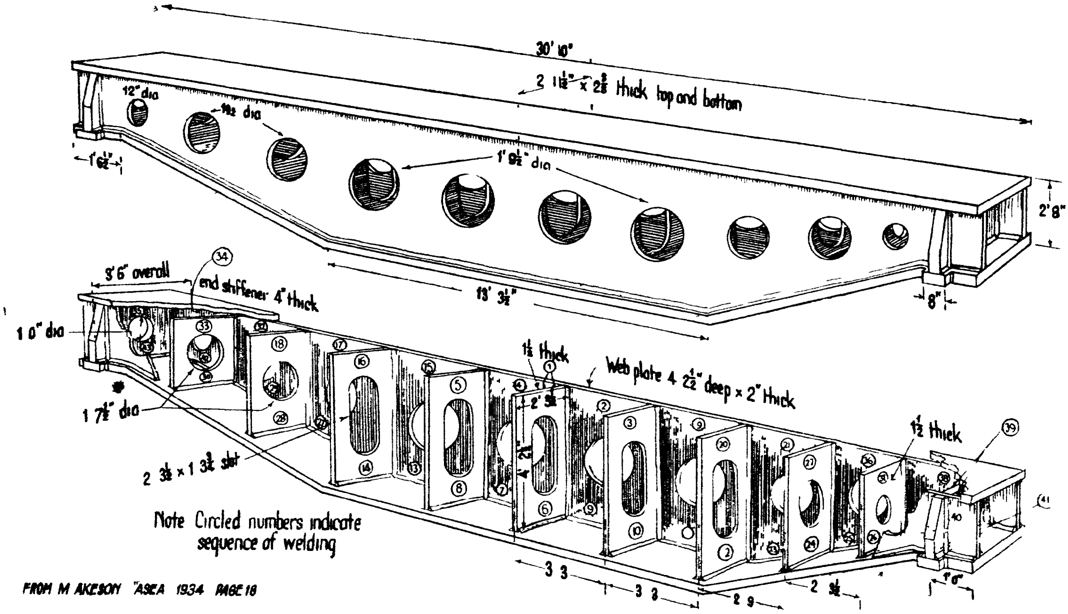
Fig. 21a. Steam Receiver—Riveted Construction

freely without causing shrinkage fissures, such castings will be in themselves good sound metal parts. But the later joining together of such castings, probably by large diameter bolts and pins, may cause awkward stress distributions. Other bed plates are formed of large single castings in which, because of the shape, weaknesses may develop in running the metal.

The welded alternative is simpler, stronger, lighter and cheaper and can be produced in a shorter time. Only if in very large quantity can the heavy casting ever compete with the welded construction in cost or speed of manufacture.

At the same time, there is no difficulty in welding most steel castings together, and a combination of castings and rolled sections is frequently good.

For the construction of all thick plate units such as that illustrated in Fig. 22 gas cutting may be used to cut the plates to their sizes or to cut openings when these are required. Welding by the metallic arc, using large electrodes and high currents, and by such procedures as will secure the weld and surrounding material from cracking (particularly in the first run) will give a very sound "welding." Reference has already been made to the reduction in weight obtained by welding, but in certain cases in which castings have been replaced by weldings it has been forgotten by the designer that a certain rigidity was required along with strength; the lightness of reduced sections can sometimes be obtained along with the desired rigidity by suitably distributed and carefully positioned stiffeners. The welds themselves need not be excessively massive; On the other hand, too small a weld, e.g. a $\frac{3}{16}$ in. throat fillet between two 3 in. thick plates, may be strong enough for a particular duty, but even when it appears to be quite sound, the weld has probably cracked along its centre and is very hard; conditions



FROM M AKESON "ASEA 1934 PAGE 18

FIG 22 HEAVY BEAM

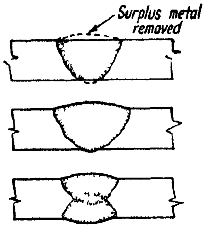
that may be revealed only after careful scrutiny of a kind that is difficult on the actual job.

(3) Structural welding is of great variety and enables the designer to use many attractive design forms in which the stress distribution is unusually well proportioned. While traditional riveted forms are not necessarily bad in welded work, they are correct and justifiable only if they permit stresses to distribute into easy natural paths. In laying the welds, the operator will find many opportunities of contributing to good form in quite important details. A few forms of weld are illustrated in Figs. 23 and 24 with the directions of stress and their weaknesses or advantages also indicated. Some are under the welder's control.

Two structural assemblies are illustrated in Figs. 25 and 26, but these cannot be regarded as even typical, the variety is so great. Designers are given much scope by the process to introduce attractive-looking forms that are also economical and efficient. The welder will also contribute his quota to economy and efficiency by making good sound well-finished welds.

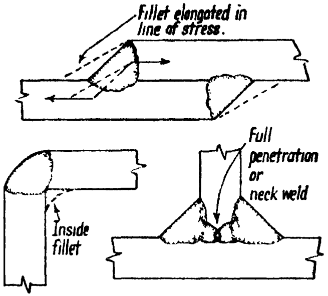
(4) Welded plate work is an enormous field for this process—ship hulls and the internal plate work for ships, tanks, ducts, flues, chimneys, gas holders, large diameter M.S. piping; all kinds of plate work in all shapes and for all kinds of duty.

An important factor in the successful manufacture of nearly all this work is the accurate cutting of parts to their size and also accurate assembly, or, in other words, accuracy of manufacture. This is usually neglected, and costs are therefore higher than they need be. It is true that the shapes of plated work are often awkward, and that the plater finds it very difficult to reduce them to known geometrical forms, and falls back on fitting parts to place. This kind of tailoring is unprofitable and unnecessary and it leads to bad welding. It is



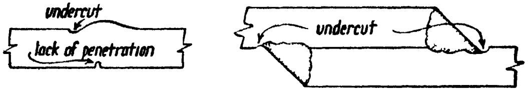
BUTT WELD – FIG 23A

Best weld form for all stress combinations
Tension, compression, bending and
alternating stresses of all kinds


Fillet elongated in line of stress.
Full penetration or neck weld
Inside fillet

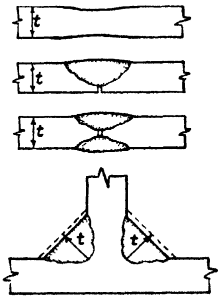
FILLET WELD – FIG 23B

Methods of avoiding or mitigating effects
of abrupt changes in stress direction



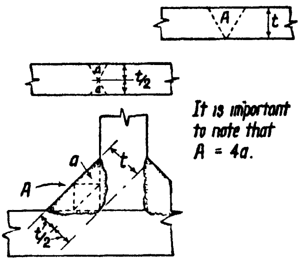
NOTCH EFFECTS – FIG 23C

Notches concentrate stresses dangerously.



SIZES OF WELDS – FIG. 24A.

Dimension "t" is always important.
Welds shown are deficient



It is important
to note that
A = 4a.

AREA AND VOLUME OF WELDS – FIG. 24B.

FIGS. 23 AND 24. WELD FORMS

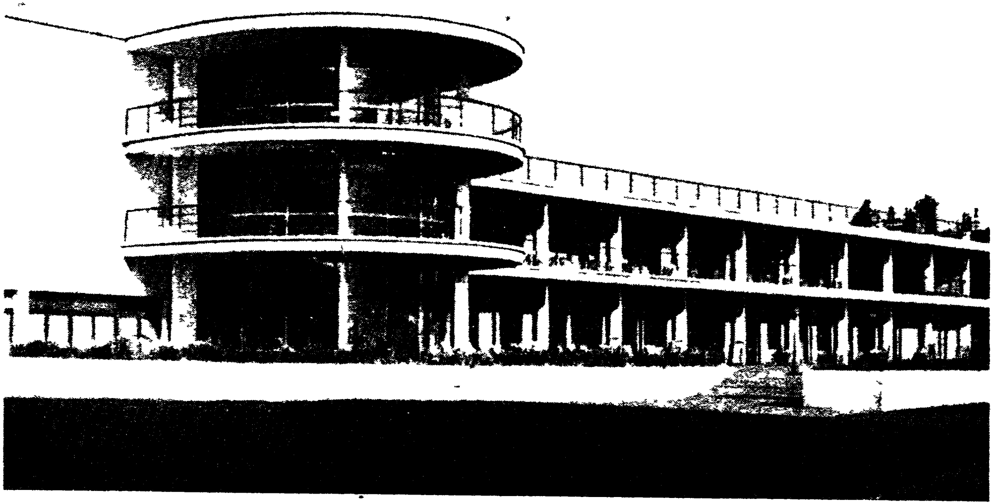


FIG. 25. STRUCTURAL ASSEMBLIES
(*Courtesy of Messrs F. J Parsons, Ltd*)

possible to reduce all plating shapes, no matter how complex, to such geometrical forms that their sizes can be calculated accurately, and the shapes of the individual parts can be cut so accurately that the welder will have little difficulty in making good sound welds; and, as is often important, the finished assembly will be accurately to size so that it fits neatly into its own place in the larger assembly, the ship, the boiler house or the building.

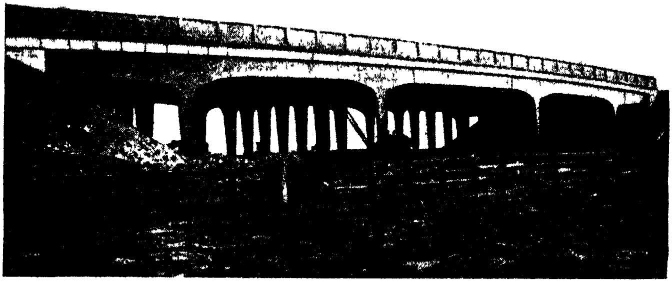


FIG. 26. STRUCTURAL ASSEMBLIES
(Courtesy of The Institute of Welding)

A single example will illustrate plate work in general. The tank illustrated in Fig. 27 had all its plates gas cut to accurate shape (with the welding bevel) on the jig shown in Fig. 28, the dome plates were rolled to spherical form, the spherical parts were assembled in a jig as in Fig. 29, and the whole was assembled with comparative ease at the site. An important part in the whole economy was the accuracy of the individual parts, although the cheap jigs used were also contributory factors to the final accuracy as well as the cost.

The examples of arc welded work given above do not cover the whole field. To do justice to the enormous amount of welded ship plating would in itself require volumes. The reader may safely assume that the present scope of this process, metallic arc welding, is already enormous and that it will expand enormously in the future

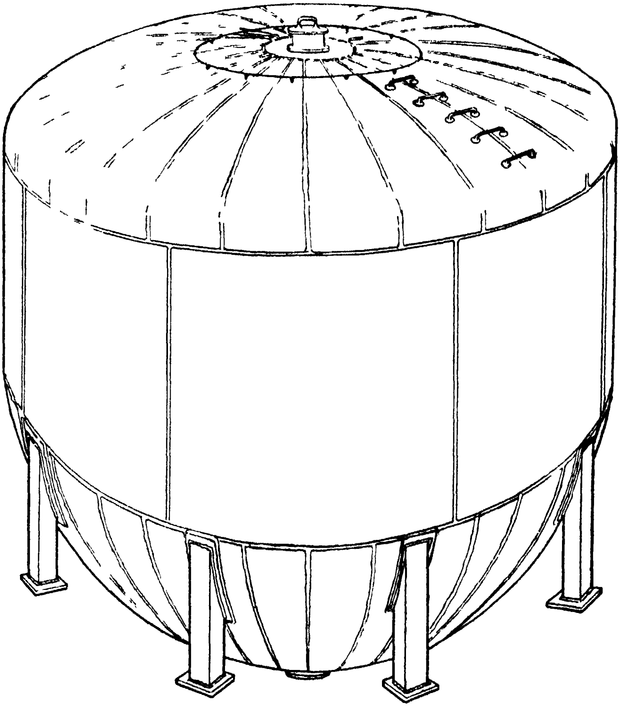


FIG. 27. ALL WELDED TANK

CARBON ARC WELDING

In this process the arc is maintained between a carbon (graphite) electrode and the job. Essentially the function of the arc is, as before, to transform electrical

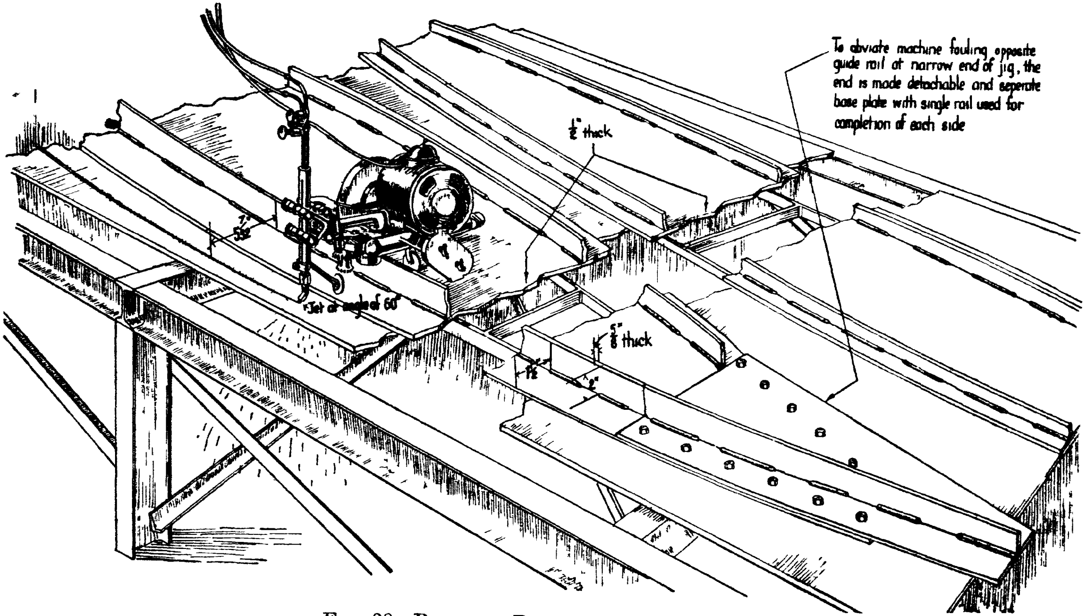

To obviate machine fouling opposite guide rail at narrow end of jig, the end is made detachable and seperate base plate with single rail used for completion of each side
½" thick
7"
5⅜"
Jet at angle of 60°
⅝" thick
1½"
2"

FIG. 28. PLATE IN POSITION BEING GAS CUT

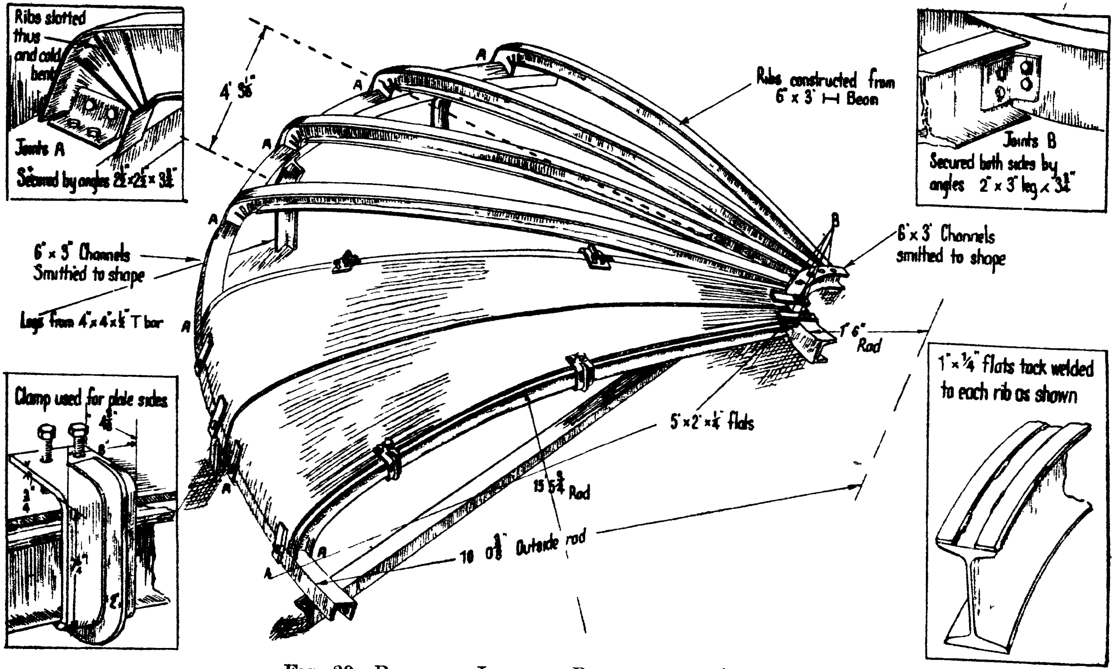

Ribs slotted thus and cold bent
Joints A
Secured by angles 2½"×2½"×3¼"
4' 5⅛"
A
A
A
A
A
A
A
A
6"×5" Channels Smithed to shape
Legs from 4"×4"×½" T bar
Clamp used for plate sides
4⅛"
6"
¾"
¾"
2"
Ribs constructed from 6"×3" I Beam
Joints B
Secured both sides by angles 2"×3" leg×3¼"
B
6"×3" Channels smithed to shape
1' 6" Rod
5"×2"×¼" flats
15' 5¾" Rod
10' 0⅜" Outside rod
1"×¼" flats tack welded to each rib as shown

FIG. 29. BUILDING JIG WITH PLATES BEING ASSEMBLED

energy into heat energy. The welder's circuit is the same as for metallic arc welding, the only difference in the composition of the whole circuit being in the composition of the electrode. One vital difference in the process is that the material of the electrode must never be carried over into the weld.

If an arc be struck between two carbon electrodes, as in an arc lamp, the negative terminal develops a point and the positive terminal a cup, and carbon is carried across the arc from the positive cup to the negative point. The cup and point are also observable in carbon arc welding; if the polarity is right, the cup is on the job and the graphite electrode is pointed. If the polarity is reversed to that usually adopted for metallic arc welding with covered electrodes, the job will then be negative and carbon will be transferred from the electrode to the job, and this will make the weld metal hard and brittle.

Alternating current cannot be used with carbon arc welding because this has the effect of producing the carbon depositing polarity during one-half of each cycle.

Apart from the fact that the correct polarity ensures against the deposit of excessive carbon, it also ensures deep penetration; the cup in the job is an indication of this fact.

Control of atmospheric contamination is obtained by the use of suitable fluxes and/or gas shields, four typical forms of protection being as shown in Fig. 30.

To control the wandering D.C. arc, a magnetic coil is introduced in the holder; this is introduced even in holders for welding thin sheets by low currents (a fairly large application of the process). The cylinder containing the magnetic coil is indicated in the illustration (Method 1).

The carbon arc has, of course, no short circuit

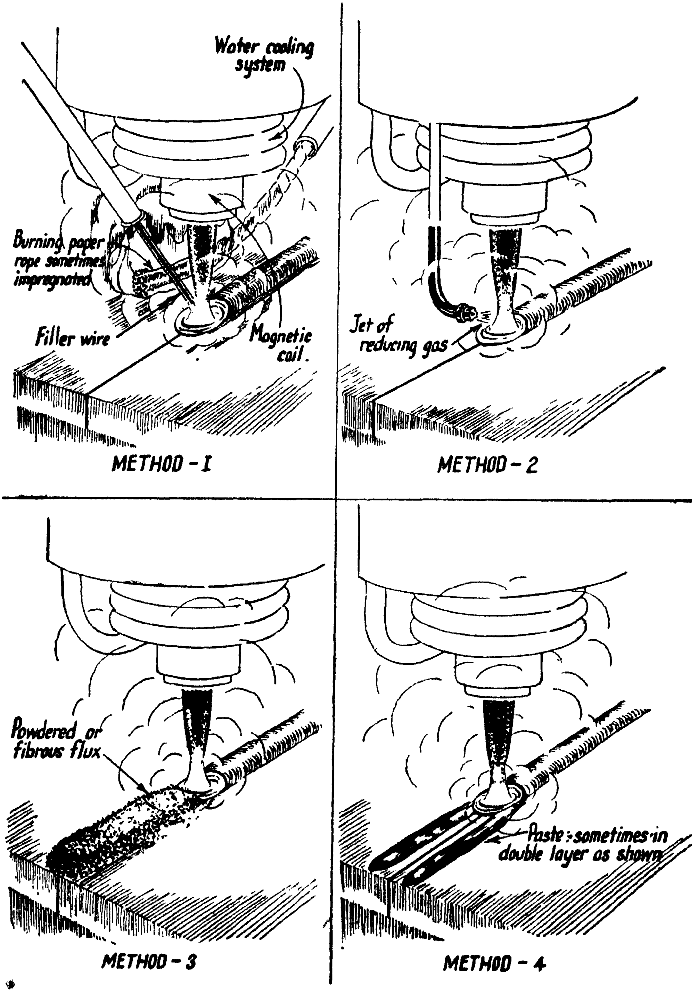


FIG. 30. PREVENTING WELD CONTAMINATION

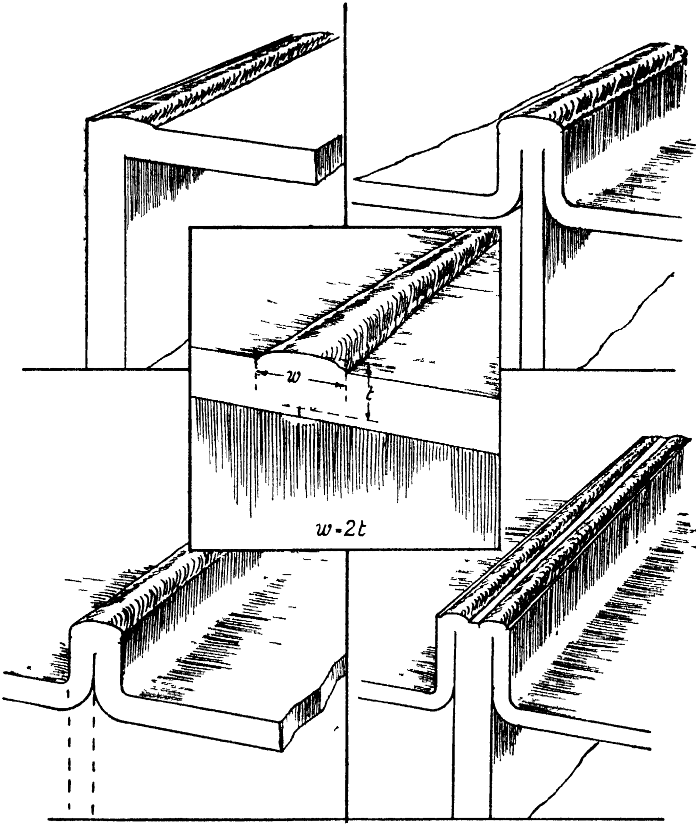


FIG. 31. CARBON ARC WELDING JOINTS

(globule bridging) period but the welding generators are of the same design as for metallic arc welding; in fact a good welding generator will serve for both processes.

Welds are usually of the forms shown in Fig. 31. It will be noted that they are of a type to which the remarks on penetration under straight butt metallic arc welding would apply. High currents can be successfully used for many purposes.

There are many applications for this process in plate work, in thin sheet work and, less justifiably, in making up deficiencies in steel castings.

ATOMIC HYDROGEN WELDING

In contrast to the arc processes already described, the job is not in the atomic hydrogen electrical circuit. The electrode holder contains two, sometimes three, tungsten electrodes through which the current flows and across the tips of which the arc plays. Actually the arc, while still the source of heat, is not applied directly to the job as the heating medium; the process is more complex.

The illustration of the apparatus for the process in Fig. 32 shows a torch (two-electrode) into which both current and hydrogen gas are passed. The hydrogen gas emerges at the tip of the torch and surrounds the tungsten electrodes, across which an arc is struck. In the intense heat of the arc the hydrogen, each molecule of which has two atoms, breaks up into the monatomic form; that is to say, the atoms become free and in so doing absorb great quantities of energy. The fan illustrated is the space within which the free atoms are ranging; as they pass across the rim of the fan

---

Explanatory Notes for Fig. 32

1 Torch
  A. Tungsten electrodes
  B. Hydrogen pipe
  C. Hydrogen pipe
  D. Hydrogen pipe
  E. Electric cable
  F. Trigger for adjusting arc
  G. Fan-shaped central flame
  H. Outer hydrogen flame
  J. Screws adjusting and fixing tungsten electrodes
2. Torch cable
3. Torch hydrogen tube
4. Push-button box
5. Push-button cable
6. Welding set
7. Control handwheel
8. Ammeter
9. Auto hydrogen valve
10. Hydrogen tube
11. Auto regulating valve
12. Hydrogen cylinder valve
13. Pressure gauge
14. Pressure gauge
15. Hydrogen cylinder

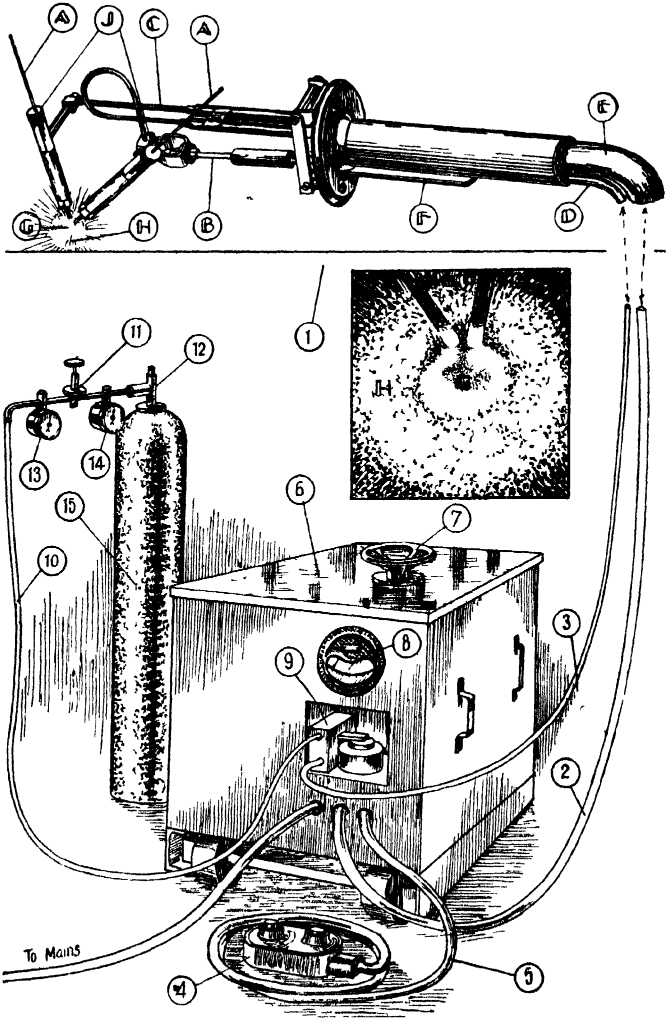


FIG. 32 ATOMIC HYDROGEN PLANT
(*For Explanatory Notes see page 292*)

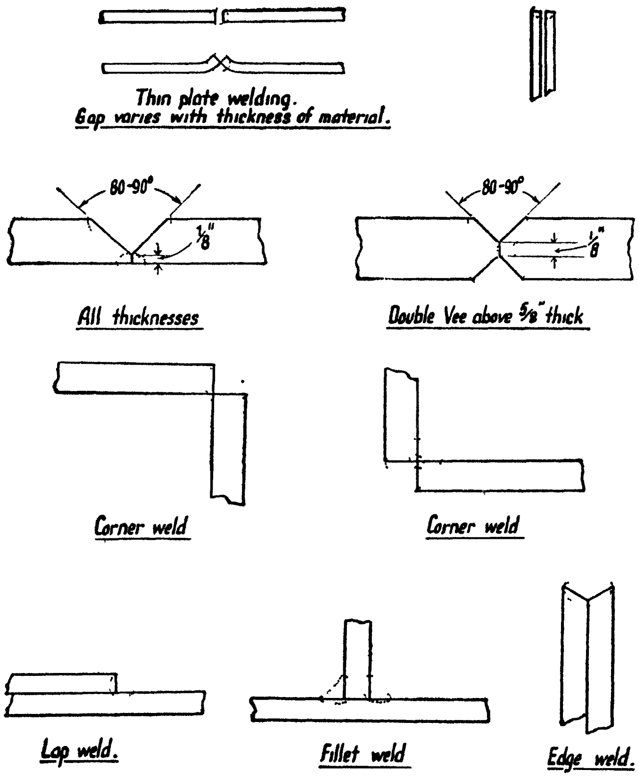


FIG. 33. ATOMIC HYDROGEN WELDING JOINTS

the atoms recombine into the molecular form of the gas and give up the stored energy in the form of heat. This rim is thus a suitable place at which to collect this heat for some useful purpose; the rim of the fan is therefore applied to the metal that is to be melted.

The current is alternating and is collected from a special transformer at a much larger voltage than either of the other processes, probably 100 volts.

Some typical welds are illustrated in Fig. 33. The applications of the process are fairly wide, but it tends to be expensive except for special applications.

GAS PROCESSES OF FUSION WELDING

The principal process in this group is oxy-acetylene welding, although for certain special low-melting point metals the oxy-hydrogen process is preferred. The practical difference between the two processes is in the degree of concentration of heat within the flame and in the resultant capacity, on the one hand, to weld economically metals of high melting temperature, and, on the other hand, to weld metals of low melting temperature and thin section neatly, uniformly and without excessive "blow through." Since oxy-acetylene welding is by far the more extensively used the following practical notes are almost entirely devoted to this process, and a brief note on the oxy-hydrogen flame and its applications is all that need then be added to indicate how this latter process may be used.

Since also oxygen and acetylene are used in oxy-cutting as well as in oxy-acetylene welding, and the quantities (particularly of oxygen) used in cutting are relatively much larger than those used in welding, the study of oxygen, acetylene and the oxy-acetylene flame is of very great importance to the engineer. It will be found that certain important and fundamental knowledge can be easily acquired and readily applied to the workshop practice, not only to obtain working economy but also to save costly accidents.

Actually, almost the whole of the present study of this process resolves itself into a study of these two gases, because the general principles already enunciated, the description of arc fusion welding processes on p. 245 *et seq.*, and the notes on metals of various kinds which appear on p. 323 *et seq.* include many features shared by acetylene welding with other processes.

OXYGEN

Earlier references have shown clearly the importance of oxygen in all welding processes, but have been confined to the danger of its presence in the vicinity of hot metal. Gas welding and cutting processes, on the other hand, use oxygen deliberately and usefully.

The fact has already been noted that oxygen from the air attacks the surface of metals and that this attack increases in speed as the temperature of the metal rises. Also it is common knowledge that combustion, for example of coal in the domestic fire, takes place as a rule more and more rapidly as the amount of air is increased, and that this is because air contains the oxygen that is necessary for combustion. The fact is that the oxidation and combustion just described are the same phenomenon, differing only in degree; actually, if enough oxygen is supplied to red-hot steel, the metal can be made to burn vigorously. This practical view of oxidation is a useful background to knowledge of many of the dangers in welding and also to the method by which gas cutting is effected. For the perfect combustion of acetylene in the oxy-acetylene flame the oxygen must be supplied in sufficient quantities.

The amount of oxygen in the world is very great: 21 per cent by volume of the atmosphere, eight-ninths by weight of the oceans and one-half by weight of the solid crust of the earth. The problem of obtaining oxygen for industry is therefore merely one of choosing the most economical method of separating it from any one of these sources. Thousands of millions of cubic feet are used by industry and the quantity grows rapidly year by year. It is nearly all obtained from the air, which is a mixture of one part oxygen to four parts nitrogen (approximately); the air is first "liquefied" and then the liquid mixture is separated by boiling off the oxygen and the nitrogen at their different boiling temperatures, — 297° F., for oxygen and — 321° F. for nitrogen.

This, of course, describes the extraction of oxygen from the air in too simple terms. The processes used may include the refrigeration of the air by external means and further cooling by sudden expansion, heat exchangers will be used to conserve power and other even more fundamental parts of the chain of processes are too elaborate for examination in this section. The essential principles in the methods used are, however, firstly liquefaction of the air and subsequently the evaporation of the constituents, each at its own suitable temperature. The gases obtained are very pure, the gas in which we are interested containing upwards of 99·5 per cent of oxygen.

Oxygen is used for many purposes (e.g. by the medical services) but the welding and cutting industry use most of the supply. It is usually delivered to this industry in cylinders at high pressure (100 to 150 atmospheres),* the cylinders being of various sizes, sometimes they are used singly, sometimes in batteries of cylinders. In establishments in which very large quantities are used, a plant of the requisite capacity is sometimes installed for the extraction of oxygen from the air and delivery by piping to the welding and cutting benches or locations.

Certain dangers in the use of oxygen are described clearly in the Home Office Memorandum, "Safety Measures Required in the Use of Acetylene Gas and in

---

* 1 atmosphere = 15 lb per sq. in.

Oxy-Acetylene Processes in Factories," to which reference is made later. These dangers can, however, be easily avoided by the user who follows closely this Home Office Memorandum. No workshop using the processes now being discussed should be without a copy of the memo, which should be available for all concerned to read and study.

ACETYLENE

Oxygen is an element, that is to say, it cannot be divided into other constituents. Acetylene is a compound, its constituents being carbon and hydrogen, two atoms of each forming the molecule of acetylene. Chemists denote this by symbols, thus C_2H_2. By weight, since the carbon atom is twelve times as heavy as the hydrogen atom, the carbon content constitutes 92·3 per cent of the compound. Not only does acetylene gas produce great heat by combustion, as its constituents divide up and combine with oxygen in the oxy-acetylene flame, but additional heat is given up by the disintegrating gas. This is because acetylene is what is called endothermic; which means that when hydrogen and carbon combine to form acetylene gas they absorb energy, and this energy is given up as heat when the gas again breaks up into its constituent parts.

Actually this quality of generating heat during dissociation (even when no oxygen is present to effect combustion) contributes to the danger associated with the use of acetylene because, once started, the process is rapidly accelerated by rising temperature. The other contributory cause is that the gas is not very stable; that is to say, it breaks up into its components very readily in favourable conditions. At low pressure and at atmospheric temperature the gas is quite stable but, even at workshop temperature, when the pressure rises to, and above, 25 lb. per sq. in. it dissociates readily and violently into its components, carbon and hydrogen. Not only this, but if the temperature of the gas is raised the pressure of dissociation falls. It is not surprising, therefore, that the generation and storage of acetylene is safeguarded by the rules to which reference has been made above.

HIGH PRESSURE ACETYLENE

For the reasons just stated it is not possible to store free acetylene in cylinders at high pressure, as oxygen is stored, and the fact that pressure cylinders of acetylene are described as "dissolved acetylene" has a special meaning. It is found that acetone (C_3H_6O), a liquid that boils at 56° C., can dissolve acetylene gas in the astonishing quantities of about twenty-five times the volume of the liquid acetone per atmosphere of pressure, and this offers a means of storing acetylene in large quantity.

Having stored the acetylene to, say, 300 times the volume of the liquid by dissolving the gas in liquid acetone, the solution having been compressed in a container to 12 atmospheres ($12 \times 25 = 300$), the gas can be drawn off by merely opening an outlet valve so that pressure is released; as the pressure drops, the liquid loses capacity for holding acetylene which flows through the outlet, the quantity of gas discharged and the drop in pressure retaining the relation indicated above.

If the container for this solution could be so designed that its whole internal volume would remain completely filled with liquid at all pressures (with corresponding acetylene contents) no danger of dissociation would arise; but since the liquid expands or contracts 4·4 per cent per 25 volumes of gas, absorbed or given out of solution, any gas extracted from the container by releasing pressure contracts the solution and leaves a space which then fills with gas that must, when the pressure is 25 lb. per sq. in. or over, be very unstable.

Thus the acetone solution is not a sufficient safeguard by itself; for this reason and as a further safeguard all dissolved acetylene cylinders are filled with a porous material (in Britain, a fibrous vegetable substance called Kapok) which divides the whole space into tiny cells in which the effects of dissociation of any portion of the gas are confined into the very small volume of its own cell. This method has proved eminently satisfactory.

Generally the porous material occupies one-fifth, and uncharged acetone two-fifths, of the cylinder volume and only two-fifths of the whole volume is available for the expansion of the liquid solution; at the maximum charge permissible by law, the combined volume of porous material and charged solution is about 87·36 per cent of the volume of the cylinder.

Thus great precautions are taken, and are necessary, to supply pressure acetylene in safe storage; and dissolved acetylene cylinders are worthily popular and extensively used. At the same time it is dangerous to expose such cylinders to sudden shock or high temperatures. Remember that acetone boils at 56·3° C. (133·3° F.) and therefore vaporizes readily at still lower temperatures, and that the porous material may be broken up or damaged by shock. Careful handling of the cylinders in cool, shady places should be the invariable rule.

LOW PRESSURE ACETYLENE

In a workshop in which several welding and cutting torches are in use simultaneously, acetylene at low pressure is often obtained by the use of a welding generator from which it is piped to the welding and cutting locations. The acetylene is invariably obtained from the reaction between water (H_2O) which supplies the hydrogen and calcium carbide (CaC_2) which supplies the carbon to form the acetylene (H_2C_2) with a residue, sludge, of slaked lime ($CaO + H_2O$).

The calcium carbide, which resembles limestone in appearance, is supplied in airtight tins. The reaction with water takes place very readily, so that on exposure to the air carbide begins to yield acetylene by combining with any atmospheric moisture that is present; for this reason the containers are opened only when required.

There are many designs of acetylene generators but the main principle, that of bringing suitable amounts of carbide and water into contact, is usually applied by, on the one hand, dropping carbide into water at a suitable rate, or, alternatively, submerging trays of carbide intermittently in a large excess of water. Special care is taken to exclude air from the reaction chamber and to prevent overheating and sparking from friction (even such as may be caused by carbide sliding over metal).

Operating instructions are supplied with every generator; they should be posted prominently beside the machine and must be scrupulously followed. They must not be treated as manufacturers' advertisements, nor is it sufficient to know roughly what they mean. The foreman in charge of the plant must know these instructions by heart and must see to it that at least one (better two) of the men on the plant is thoroughly versed in its operation and care, laying special stress on the dangers pointed out by the instructions. If generators are obtained second hand, it is worth while taking a considerable amount of trouble to obtain the correct instructions for the plant; this will contribute as much to economy as to safety.

Cleanliness of the parts and disposal of the sludge are always important, as is also the maintenance of the prescribed amount or flow of water; a special function of the water will be as a coolant. Reference has already been made to the Home Office Memorandum, "Safety Measures Required in the Use of Acetylene Gas and in Oxy-Acetylene Processes in Factories." The following notes indicate, rather inadequately perhaps, its value to the welder and his foreman, because it contains much useful and practical information on this subject.

1. Acetylene-air mixtures, with acetylene 2 per cent to 58 per cent, are explosive.

2. Generators should work at a pressure of not more than 60 in. water (i.e. 2·2 lb. per sq. in.) unless under special circumstances. Pressures higher than 250 in. of water (about 9 lb. per sq. in.) are forbidden by Order in Council.

3. The metal of fittings must not contain more than 80 per cent of copper because acetylene reacts with copper to form a highly explosive compound, copper acetylide. Blowpipe tips are excepted from this rule.

4. Half-spent carbide is likely to be very hot and acetylene ignites spontaneously at 480° C.

5. Sparks from the friction of carbide falling down chutes may cause explosion.

6. Sudden incandescence of carbide dust may be the cause of explosion.

7. Obstruction in a blowpipe nozzle may cause oxygen (always at higher pressure than acetylene) to blow back along the acetylene pipes, making an explosive mixture.

8. Molten drops of slag or metal or particles of mud or paint may choke a nozzle and cause back firing; this tendency will be aggravated if the nozzle is overheated. (The nozzle may be cooled by dipping it in a bucket of cold water.)

It will be observed, therefore, that the Memorandum calls attention to the dangers inherent in the use of acetylene. It also recommends or makes compulsory good practice in the operation of generating plants.

1. Baskets of dipping type generators should be charged entirely with fresh carbide at each start up.
2. Before repairs the whole apparatus should be flooded with water and repair should be carried out immediately thereafter.
3. Ample ventilation is essential in generator houses, workshops and welding locations.
4. Hydraulic back pressure valves must always be in good working order, with water at the proper level; daily attention is necessary.
5. Regulators on high pressure cylinders must always be in good working order.

The dangers to which the Memorandum calls attention appear to be so numerous and important as to embarrass use of the process. Actually, the manufacturers of generator plants offer many automatic safeguards, and if these machines are operated to instructions dangers are avoided; so that acetylene is generated and used successfully and safely in great quantity in thousands of workshops in all industrial communities. The important thing is that foolish risks should not be taken by operators or plant fitters or foremen because of ignorance; such, for example, as the use of a copper tube to connect an extension to a rubber hose containing acetylene (see danger (3) noted on p. 302).

THE WELDING FLAME

The purpose of the welding flame is usually to produce a highly-concentrated source of heat which can be applied to the local heating of metals of high melting temperature in much the same way as the electric arc or in more truly the same way as the atomic hydrogen

flame. The temperature of the welding flame is one of the most important factors.

FLAME TEMPERATURES

Gas	With Oxygen	With Air
Acetylene .	3120° C.	1755° C.
Hydrogen .	2300° C.	1700° C.
Coal gas .	2000° C.	1600° C.
Butane .	2730° C.	1750° C.
Propane .	2500° C.	1750° C.

In the gas welding of such metals as steel, nickel and copper and in the preheating for oxy-cutting of steels, the oxy-acetylene is the most popular and efficient of these flames. Occasional variations in the oxy-cutting preheat flame by the combustion in oxygen of gas mixtures, such as acetylene with coal gas, reduce the speed of cutting, but sometimes make it easier to secure machine finish in the "cut." Also, as mentioned earlier, the welding of thin sections of aluminium and aluminium alloys can frequently be simplified by using less intense welding flames; for instance, the oxy-hydrogen flame may be deliberately chosen for such a weld.

Fig. 34 illustrates four types of oxy-acetylene flame. The first is obtained when the welder turns on acetylene and lights it (at a pilot jet or a smouldering rope lighter, not with a match); acetylene should always be "on" before oxygen so that there is no danger of oxygen leaking into empty acetylene pipes, also lighting usually precedes the opening of the oxygen valves. Acetylene pressure must be sufficient to separate this first type of flame from the nozzle tip as shown. In this case acetylene is burning in air. The second flame is obtained by opening the oxygen valve progressively until a white core of the form illustrated has formed at the nozzle tip. The third flame requires still more oxygen, now roughly equal in quantity to the acetylene.

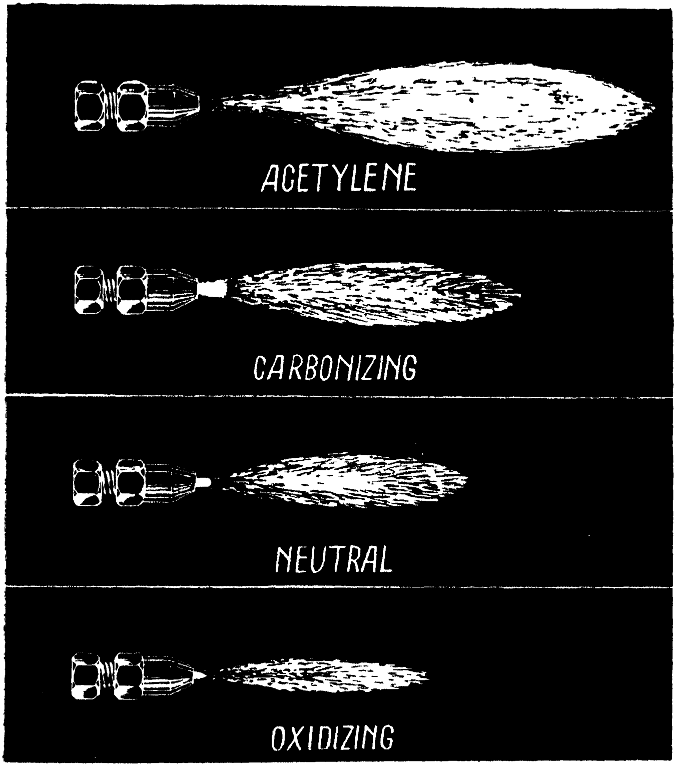


FIG. 34. FOUR TYPES OF OXY-ACETYLENE FLAME

In the fourth, the oxygen, increased still further, is in excess. The second, third and fourth flames are of importance in welding. Their names indicate the balance of the gases; the "carbonizing" flame takes excess carbon from an excess of acetylene, the "oxidizing" flame has an excess of oxygen, and the neutral flame has balanced quantities of both oxygen and acetylene. The appearance of the flame is a reliable indication of the gas mixture and the welder can therefore adjust the proportions accurately without further test or trouble.

In the neutral flame approximately equal quantities of the gases are mixed in the torch and emerge at the tip, and since complete combustion of any quantity of acetylene requires 2·5 times as much oxygen, the remainder of the oxygen is obtained from the atmosphere. When the oxygen proportion in the torch mixture is increased or decreased the quantity of oxygen that must be obtained from the air is also altered. These variations in the gas quantities have a practical significance in the welding flames illustrated. Firstly, combustion is by two stages, the inner core and the outer flame; secondly, the form of the inner core depends entirely on the proportion of oxygen to acetylene in the torch mixture; thirdly, the size of the outer flame depends on the amount of combustion of acetylene-in-air taking place in this outer zone of combustion. Fig. 35 illustrates the steps in combustion and indicates the reactions taking place. Practically all the heat in the flame is given up by the inner core so that this heat can best be collected for welding just outside this intensely hot little zone; this is the point of application for the flame in welding, because the inner core supplies the heat to melt the metal and the outer flame, which is relatively quite cool, serves merely to protect the weld from atmospheric contamination.

The neutral flame may be considered the correct flame for welding metal that is free from rust or scale, but when such oxides are present a slight excess of acetylene is required for their reduction. The oxidizing flame is not likely to be required for any welding purpose because the excess oxygen combines with the metal in forming metal oxides, which are always dangerous.

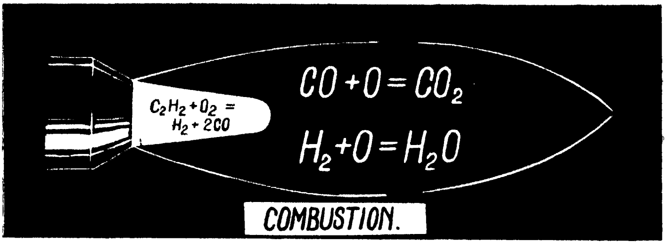


FIG. 35. FLAME REACTIONS

Thus, a slightly carbonizing flame is necessary for practically all welding purposes.

THE PLANT LAY-OUT

The arrangement of plant shown in Fig. 36 includes high pressure oxygen cylinders and dissolved acetylene cylinders supported in a suitable frame, regulators and pressure gauges, piping and the welder's torch. It will be noted that the cylinders are set up vertically; this is the best position in most cases. Sometimes batteries of large cylinders have to be placed horizontally but they must be kept clear of all dangers, such as crane lifts, etc. The oxygen regulator is black and the pressure gauge is graduated in atmospheres, the acetylene regulator is red and the pressure gauge is graduated in lb. per sq. in. The torch or blowpipe should be of the high or medium pressure type because in these torches the gas mixtures are more accurately under control and can be used more economically; also these torches are fitted with a back pressure device (in place of the hydraulic back pressure valve for low pressure systems). All welding torches consist essentially of an inlet for each gas, a mixing chamber and a nozzle through which the gases emerge after mixture. The tips of the nozzles are usually removable so that each torch may be used for a large variety of weld sizes.

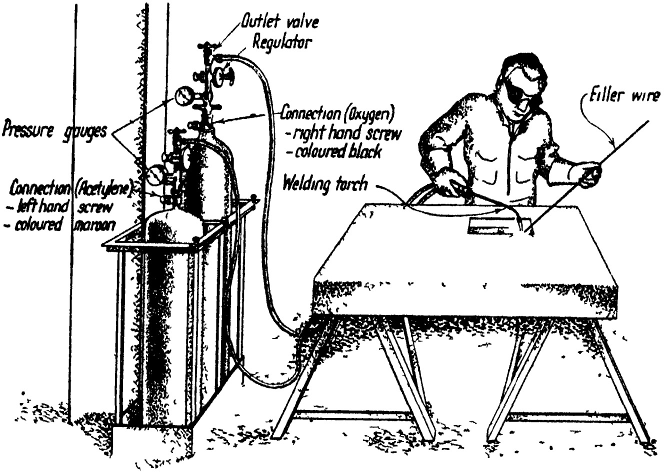


Fig 36 High Pressure Plant Lay out

The low pressure lay-out is indicated in Fig 37 The generator consists essentially of the generator chamber (and its mechanism), the storage chamber (with such mechanism and seals as may be required) and a back pressure valve , in addition, means of gas purification and cooling are essential Copious supplies of water for cooling the plant as well as for gas generation and a regular supply of good and consistent quality carbide complete the working requirements The lay-out is not intended to show the details of the generator because each user must get to know his own plant intimately

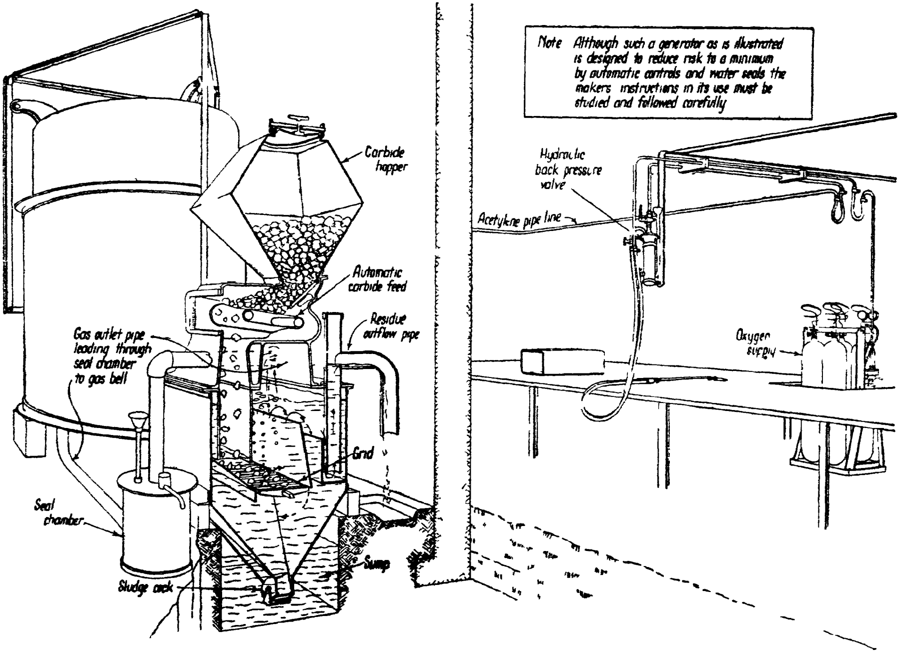

Note Although such a generator as is illustrated is designed to reduce risk to a minimum by automatic controls and water seals the makers instructions in its use must be studied and followed carefully
Carbide hopper
Automatic carbide feed
Residue outflow pipe
Gas outlet pipe leading through seal chamber to gas bell
Grid
Seal chamber
Sump
Sludge cock
Hydraulic back pressure valve
Acetylene pipe line
Oxygen supply

FIG 37 LOW PRESSURE PLANT LAY OUT
(The generator illustrated is by C S Milne & Co)

from the manufacturer's instructions, not from general notes such as these now being given. The oxygen supply varies with the conditions as mentioned above. The low pressure torch is of the injector type; high pressure oxygen sucks low pressure acetylene into the mixing chamber.

Three practical working precautions should be mentioned in considering the care of plant. Firstly, always remember that nozzle tips have very tiny openings that are easily choked and also easily enlarged; therefore the cylinders should be cracked before connecting the hose and the hose should be blown through (with the nozzle or tip detached from the torch) at suitable intervals, and the utmost care must be exercised in cleaning nozzle tips to ensure against enlarging or altering the shape of the opening. Secondly, oil, grease and dust must be kept clear of the oxygen supply; oxygen combines with nearly all substances, violently with some, and these mentioned are dangerous; such combination may cause a burst of flame or an explosion. Thirdly, never pass oxygen or compressed air through an acetylene hose; the range of the explosive mixtures of acetylene with oxygen and air is very wide (as indicated above).

JOINTS

Many of the oxy-acetylene welding joints resemble those used in metallic arc welding. Penetration is less effective and varies with the skill of the operator, so that the welding gap in straight butt welding must be greater and thicknesses of more than $\frac{5}{16}$ in. are seldom attempted with this type of weld. Generally speaking, veed butt welds and outside fillets are very effective. Inside fillets can be made quite effectively if the angle is not too narrow (say less than 60°). As in arc welding, fusion at the root and other features of good form, i.e. weld metal at the right place, must be obtained. The amount of metal that is raised to temperatures that affect distortion is greater than in arc welding, and this must be borne in mind; in some cases this is an advantage but it is often disadvantageous.

Typical welds are illustrated in Fig. 38. The "rightward" method of deposition is compared with the "leftward" method in Fig. 39; the former is much faster and is now almost universally favoured. In rightward welding the flame is nearly always of the carbonizing type and the strength of the metal is usually found to be somewhat higher.

A tendency to overheat steel by keeping it at high temperatures for long periods, particularly when building up on thick sections, should be guarded against. Apart from the enlargement and separation of the grains referred to earlier, prolonged overheating may also cause serious loss of carbon.

APPLICATIONS

The applications of the oxy-acetylene process are very wide, but for many practical reasons this process is seldom used extensively in making welds which can be effectively welded by the metallic arc. On the other hand, oxy-acetylene welding is more effective than arc welding (to date) for welding many of the non-ferrous metals and for most cast-iron welds. The process has also a special field in repairs and in the building up of hard surfacing metals.

OTHER WELDING FLAMES

Oxy-hydrogen and air-acetylene are the other flames most commonly used in welding. Fig. 40 illustrates these beside the oxy-acetylene flame. In contrast to the oxy-acetylene it will be noted that the inner core of these alternative flames is ill-defined or completely

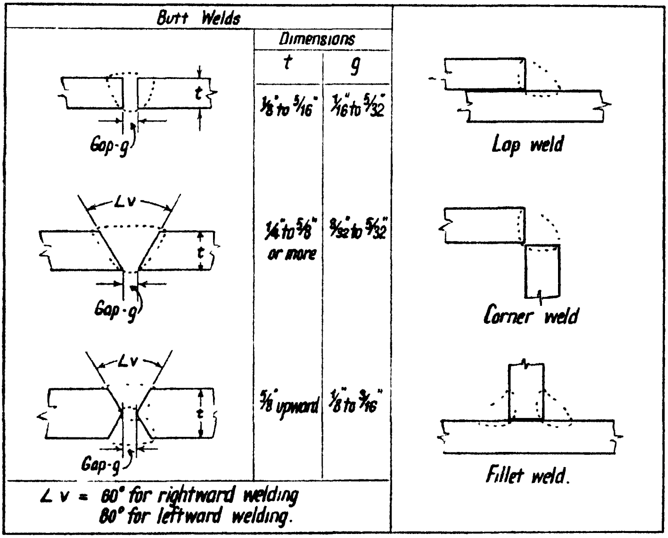


Fig. 38. Gas Welding Joints

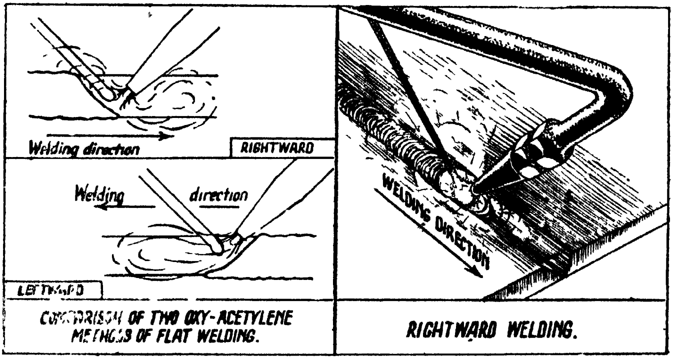
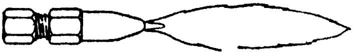
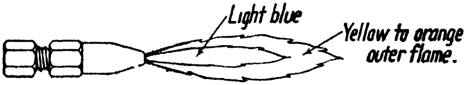


Fig. 39. "Rightward" and "Leftward"

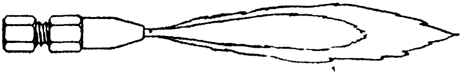
absent; the differences correspond with the fact that the concentration of heat is becoming progressively less definite. These other flames are, as already indicated, applied only to low melting temperature metals, the air-acetylene being used only for soldering.



OXY-ACETYLENE NEUTRAL FLAME.
See fig. 34 for variations.



OXY-HYDROGEN NEUTRAL FLAME.
As size of flame decreases internal flame increases proportionately and the colour of the outer flame fades as the oxygen proportion increases.



AIR-ACETYLENE FLAME.
See fig. 34 in which all air is from the atmosphere.
In the flame illustrated above, the mixture of air and acetylene takes place in the nozzle.

FIG. 40. CONTRASTED GAS FLAMES

GAS CUTTING

Reference has already been made at several stages of the study of the processes so far discussed to the oxidation of iron and to the increasing rapidity of this oxidation as the temperature of the metal rises. It will also be understood that oxidation will be speeded up by any increase in the amount of oxygen brought into contact with hot iron. If, therefore, we replace the still air in which red-hot steel rapidly forms scale by a jet of pure oxygen blown across the red-hot steel, exceedingly rapid oxidation may be expected and combustion actually takes place. This is the method by which gas cutting is effected; the red-hot metal is parted by a jet of oxygen which burns the metal into oxide and blows the oxide clear. The process is very effective on steels, upwards of 24 in. thick being commonly "gas-cut" and thinner sections often cut with great precision.

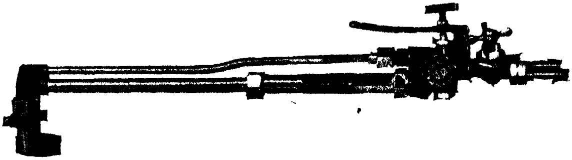


FIG. 41. HIGH PRESSURE M.S CUTTER

(British Oxygen Co., Ltd.)

The temperature at which mild steels and low alloy structural steels are combustible in pure oxygen as described above is about 900° C. The nozzle contains two or more jets, one of which passes pure oxygen and the others pass mixtures of gas that provide oxy-acetylene preheating flames. Fig. 41 shows the typical torch. The preheating flames are first lit and directed on the edge of the metal to be cut; then when the metal is raised to the necessary temperature the oxygen jet is turned on, combustion takes place and the oxygen jet begins a cut which, by progressively moving the nozzle along any desired direction, parts the metal to the shape required. The heat of combustion combines with the heat of the preheating flame to keep the metal ahead of the oxygen jet at the temperature of combustion. The former source of heat supplies by far the greater portion of preheat required.

The plant for oxy-cutting is similar to that used for oxy-acetylene welding, but the oxygen supply must be very much greater; batteries of oxygen cylinders are usually required when thick pieces are being cut in large quantities. As it is a great advantage to keep the speed of movement of the oxygen cutting jet perfectly regular, mechanical means of obtaining the control of the speed are often used in what are called automatic gas cutting machines. These machines are also designed in many cases to cut great varieties of shapes, often to a templet round which a magnetic guide roller traces out the shape to be followed by the cutter, although in many machines the operator can himself trace the shape on a simpler templet or drawing if the quantities are small. In each case the machine contains mechanism that repeats at the nozzle the movements of the roller or the operator's hand.

A simple automatic machine was indicated in Fig. 28, and other more elaborate machines are illustrated in Figs. 42 and 43.

In the practice of cutting, several special precautions should be noted as contributory to the good finish of a particular cut (see Fig. 44).

1. The jet (and the flame) should be at right angles to the job.
2. A too large preheating flame tends to melt the upper surface so that it fuses behind the cut.
3. Too much cutting oxygen burns too much metal in the upper portion of the cut surface (although the bottom part of the surface may be quite smooth).
4. Excessive speed curves the drag lines backward. Further increase aggravates the tendency until the cut is lost.
5. Inadequate speed undercuts the upper surface and "pipes" the lower portion of the surface of the cut.
6. Nozzle too high causes a mixture of part of the

oxygen with the preheating mixture, the upper surface melts and fuses.

7. Nozzle too low completely unbalances the cut; it is rough and the upper surface is probably grooved and has melted.

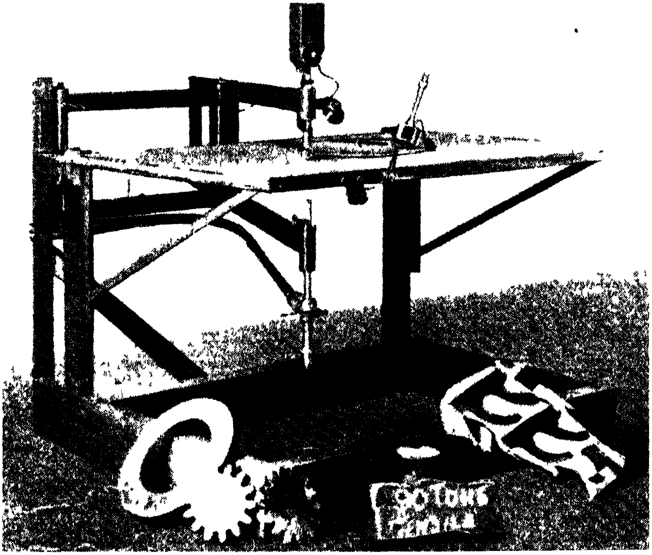


FIG. 42. A TYPICAL MEDIUM DUTY GAS CUTTING MACHINE

(By Sir Wm. Arrol & Co., Ltd.)

As was shown in Fig. 28, the cutting of welding bevels by the oxy-cutting process is not difficult; it is merely necessary that the oxygen jet should be set at the necessary angle.

To pierce a plate at a given point, the preheating flame should play on the spot until the metal is at the necessary temperature; the oxygen jet should then be turned on, slowly at first, the jet being built up gradually so that metal and slag may not be spattered on the nozzle.

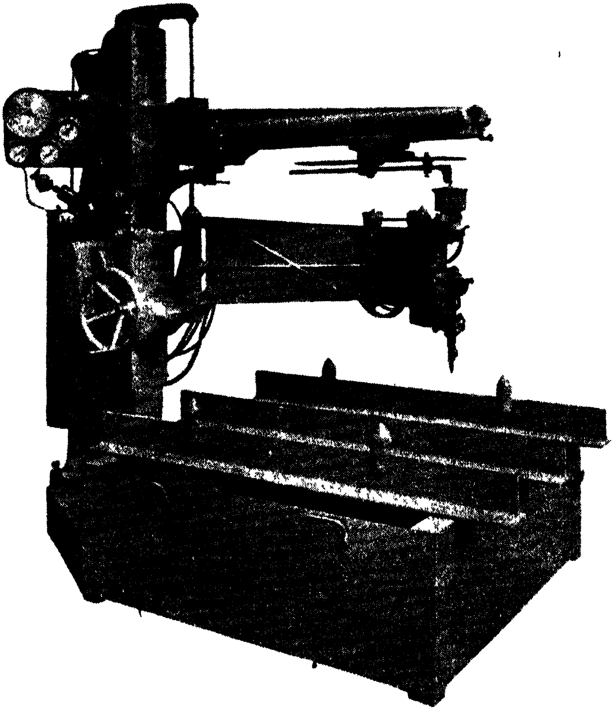
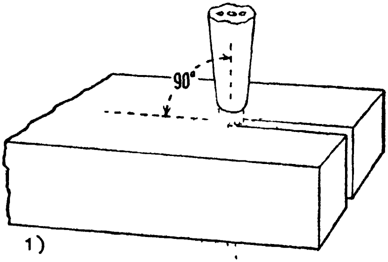
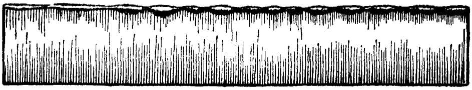


Fig. 43. A Heavy Duty Gas Cutting Machine: The British Oxygen Universal Gas Cutter

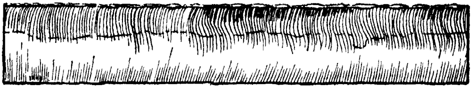
In cutting a hole in a plate, a starting hole may be pierced as described inside the area to be cut out and the jet can then be moved to the boundary of the shape to be cut out and the cut proceed.



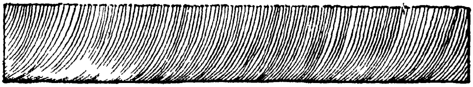
1)



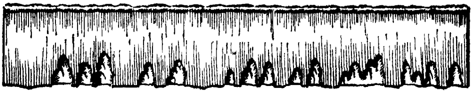
2) Excess heating flame. top surface fuses



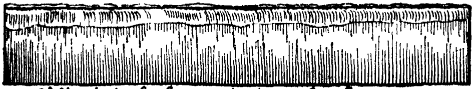
3) Excess oxygen· concave at top surface



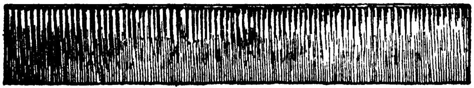
4) Speed too fast.



5) Speed too slow: undercut.



6.) Nozzle too far from work: top surface fuses.



7.) Nozzle too near work: top surface grooved and melted.

Fig. 44. Gas Cutting Effects

Straight edge guides, compasses, and many other hand steadying devices are commonly employed to make possible almost machine-cut precision in manual gas cutting, and the use of small portable machines (as in Fig. 28), sometimes thirty or forty at a time running about the floor of a single workshop, is gaining favour for the cutting of large plates of irregular shapes.

Gas cutting of steels of higher alloy content requires progressively increasing amounts of preheating as the whole cooling mass increases and the alloy content increases. Otherwise the stresses caused by expansion and contraction combined with the increasing brittleness of the material may cause serious fractures. The local heating of gas cutting has also the same distortion effects as welding, as will no doubt be readily understood; these must be kept in mind and allowed for. In particular cases, although the path set for a machine may be precisely accurate, the shape of the piece after cutting may be quite different from that of the templet or drawing, owing to movements within the material as rolling strains are released, or to distortion caused by the expansions and contractions during cutting. Owing to such movements, allowances for subsequent machining have often to be made.

Gas cutting of cast iron requires a special technique. The metal has to be raised almost to molten temperature before combustion takes place and the width of the cut has to be increased in order to clear the mixture of molten and oxidized metal. The nozzle is therefore oscillated as shown in Fig. 45 and moved from the angle of starting to the angle of cutting as shown. The width of the cut varies with qualities in the metal and with the skill of the operator. The variety in quality and chemical content of cast iron also calls for other slight variations in the method of cutting which are always, however, generally as described.

THERMIT FUSION WELDING

A description of fusion welding processes is not complete without some reference, however brief, to this process. Thermit is a mixture of aluminium and iron oxide. If heated to about 1550° C. the mixture ignites and as the aluminium unites with the oxygen in the oxide, molten iron is freed and can then be drawn off in a superheated condition (the temperature of the mass being given as over 2500° C.).

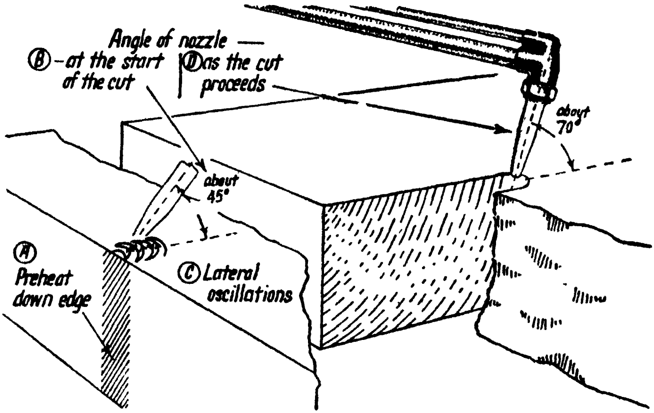


FIG. 45. CUTTING CAST IRON

The whole operation is essentially a moulding operation in which the superheated molten metal is poured into a mould surrounding the ends of the parts to be welded. The parent metal surfaces are melted and fuse to the added metal. It is used for welding rails, as shown diagrammatically in Fig. 46.

BRONZE WELDING

It is emphasized later that certain metals are difficult to weld, and two of the major reasons given are—

(1) that certain metals are very brittle so that the distortion due to weld shrinkage tends to cause fractures in the weld "junction", and

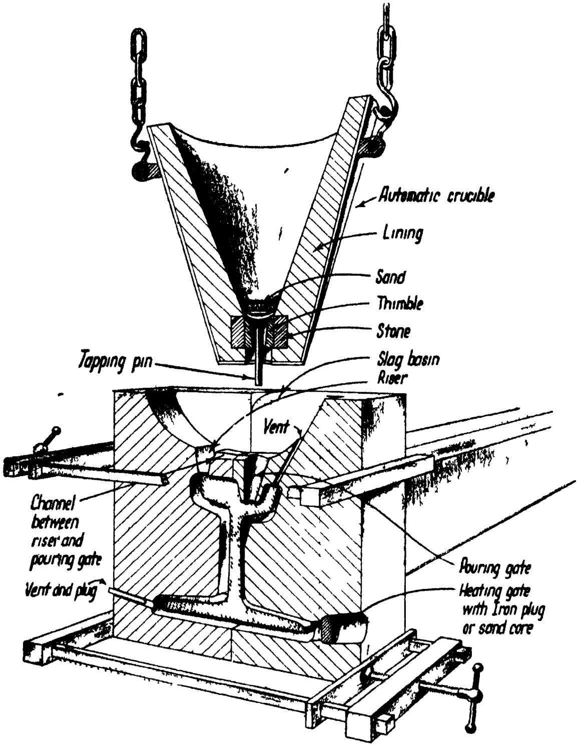


FIG 46 THERMIT WELDING

Schematic illustration of crucible and joint Mould sectioned and one rail removed

(2) that certain metals tend to lose to a large extent their components or properties if raised to molten temperature.

If some weld metal could be found that would deform by yielding plastically to the weld shrinkage during cooling, until quite low temperatures were reached, the first difficulty would be met; because the non-ductile parent metal would be relieved of most of the residual stresses that cause fracture. Bronzes yield in this way.

If sound welds could be made at sub-molten temperatures, particularly in those metals that rapidly lose their quality at molten temperatures, the second difficulty would be met, bronze welding makes such welds.

In bronze welding, only the filler metal used need be molten; the parent metal need usually be only at a temperature of 900° C. or a little higher. The best heating media are the oxy-acetylene flame and the carbon arc. A flux is used and the edges of the parent metals are "tinned," by the bronze, after which metal from the bronze rod is laid into the groove as for any gas weld of similar type.

The weld is strong and fairly ductile; as a solution to the welding of difficult metals such as cast iron and some steels it is at least as effective in mechanical properties as any alternative. The strength of the weld varies with the conditions of welding and the type of welding rod used; this filler metal may be of phosphor bronze or Monel metal in arc welding or of straight copper zinc with certain modifications (tin, iron, manganese or silicon) when used with the gas flame. It is usually best to purchase the filler rod or electrode from a manufacturer of such material whose experience is a useful guide to the best type for each metal and weld. Otherwise, important welds should be carefully considered and the procedure decided after careful test.

When using the metallic arc (for instance, in welding certain bronzes) the flux is contained in the electrode coating. This application of the process is more truly of the fusion class but the fusion penetrates only slightly into the parent metal.

WELDING VARIOUS METALS

The variety of the metals that may be presented for welding is very great, and while it is impossible to give in the scope of this section comprehensive information as to the properties and behaviour of these metals under welding conditions, the following notes may be of service if they indicate certain tendencies and point out certain dangers and pitfalls to welders and their foremen.

IRONS AND VARIOUS CARBON STEELS

Wrought irons and **low carbon irons** are easily welded by all the fusion welding processes. The melting temperatures are always high, about 1518° C., and it is necessary to make sure of fusion; on the other hand, since these metals lend themselves to high rate of heat input and fast welding, good fusion should never be difficult. When welding by the oxy-acetylene processes the filler rod usually contains manganese and silicon in suitable quantities so that the necessary fluidity of the metal is secured; in addition, these elements contribute to the strength of the weld metal. The oxy-acetylene flame should be neutral. In welding by the metallic arc process high currents and fast speeds should be the rule, and good shielding from atmospheric contamination is an advantage in this as in other metals.

Wrought iron and other low carbon irons tend to absorb gases readily at high temperature, and for this reason it is advisable to restrict the molten period without loss of the necessary fusion. In arc welding these results are best obtained by using the high currents and fast speeds already recommended. Embrittlement due to too rapid cooling is never a serious factor in these metals and preheating is never necessary. Also, since the metals are very ductile, there is little call for stress relief.

The slag in wrought iron may deceive the welder because it melts at a temperature considerably below the melting temperature of the metal; the metal must be melted and the slag brought to the surface, otherwise metal fusion will be incomplete.

The best indication of when the metal is actually molten is a glassy appearance on the surface of the weld.

Low carbon steels with carbon content up to 0·3 per cent are also welded very easily by all the fusion welding processes. High rates of heat input and fast speeds generally give the best results, and if the cooling mass of the job is large, and the carbon content is tending towards the upper limit mentioned, the welding procedure should ensure that the rate of cooling is not so severe as to cause chilling. Such chilling is almost impossible in using oxy-acetylene welding, in which a carbonizing flame and rightward welding will almost invariably give good results. In arc welding these metals, embrittlement due to chilling becomes serious only if an attempt is made to weld with small runs of metal on very thick plates or sections.

In very cold weather the starting point of a weld may be heated with profit to about 100° C.; this will eliminate any danger of chilling. Stress relief is applied to pressure vessels and is sometimes carried out on welded structures that have been designed to withstand severe service stresses. A common rule for this stress relieving heat treatment is to heat the whole structure to 600–650° C. and hold this temperature for about one hour per inch of thickness. The temperature of the whole mass should be kept uniform during cooling.

Oxide and slag will be excluded from the weld by the choice of suitable electrodes and a suitable welding procedure. Gas content will be kept to the minimum by the use of high rates of heat input and slow cooling methods. Major inclusions should, however, cause little trouble if the welding procedure is carefully chosen.

Medium carbon steels. When the carbon content of *plain carbon steels rises above about* 0·3 *per cent,* the danger of embrittlement due to chilling (as described on p. 243) becomes important. Steels containing carbon up to 0·5 per cent have been welded successfully without special precautions when the parts being joined were free to move with the welding contractions; but, generally, preheating is necessary as the carbon content rises and as the cooling mass increases. In light-weight sections in which the carbon content does not exceed 0·4 per cent it may be found sufficient to preheat to 100° to 150° C., but for heavy sections, and as the carbon rises towards the upper limit of the range (0·5 per cent), preheating to 250° or 300° C. will often be found necessary.

Since the metal is intrinsically harder and more brittle than mild steel, the residual stresses which are inevitable in welding must be taken account of and, in addition to preheating, step welding and other procedures that control stress distribution should be adopted freely. The high rate of heat input recommended above will also be applicable in this case provided it is combined with a wide distribution of the welding heat so that the stress gradient at high temperature is not too steep.

Such metals may, before welding, have been heat-treated, for example, by quenching and tempering; this increases the necessity for caution during welding; it will be advisable in many such cases to normalize the parts and to give them a suitable heat treatment after the welding is completed. When this more elaborate treatment is unnecessary or impossible, relief of the residual stresses may be attended to by heating to at least 400° C., followed by uniform cooling.

Oxy-acetylene welding of the metals just described should be by a carbonizing flame. Arc welding should be with a high tensile covered electrode, and as the heat in the arc is so highly concentrated, the precautions against chilling and residual stress may have to be more rigidly observed. The procedure for each case should be established by careful test, particularly if the service duties of the welded part impose severe stresses on the weld or the metal in its vicinity.

High carbon steels (carbon 0·5 per cent to 0·9 per cent) are difficult to weld. With oxy-acetylene welding use a carbonizing flame and a medium carbon filler rod; preheat and weld quickly. In arc welding preheat must be to at least 350° C. As in the previous group, the metal may require heat treatment (normalizing) before welding, with possibly subsequent treatment by normalizing and tempering.

Thus, the variable factors in the welding of plain carbon steels are carbon content and cooling mass, the other factors in good welding practice remaining fairly constant through the series.

Copper bearing steels of the usual 0·3 per cent (maximum) carbon and 0·3 per cent copper present no difficulty. They are welded by the same procedure as plain carbon steels of equivalent carbon content.

Cast iron presents special difficulties because it is brittle and relatively weak, and because the weld is never of homogeneous metal. The aim in a cast iron weld is to produce strong but ductile weld metal and to ensure that the junction between the weld and the cast iron is not fractured by the contraction stresses of welding.

In general, iron castings should be preheated to a dull red and welded at this temperature. Cast iron filler metal for gas welding should be high in silicon, and a flux should be used to remove oxides. In arc welding, the flux is supplied in the electrode coating. The welded piece should be cooled slowly. After arc welding it will sometimes be necessary to anneal. The arc weld should be in short (2 in. to 3 in.) runs, with low current. Stresses are reduced by lightly peening each run.

Preheating will usually be unnecessary in bronze welding, although a slight preheat will certainly facilitate the "tinning" of bronze on the cast iron parent metal. Tinning takes place when the cast iron is at 800° to 900° C. (compared with fusion at about 1200–1300 C.). This process produces good strong machinable welds. The yielding qualities of bronze, referred to in the notes on bronze welding on pp. 320 to 323, make this process specially valuable in the welding of these non-ductile cast irons.

Low alloy high-tension steels of the 38 to 43 tons range used in structural work are usually weldable by the procedures commonly used in the welding of mild steel, but the danger of cooling embrittlement is increased by the higher strength and higher alloy content. In welding these steels the distribution of the high temperatures in and around the weld must be wide and the rate of cooling must not be too fast. This does not mean that preheating is necessary in all cases and, in fact, preheating can often be avoided by using a suitable welding procedure. In many welds the use of high current and large electrodes keeps up the temperature of the surrounding mass sufficiently to retard cooling and prevent severe local stress variations.

The electrodes must be suitable and, unless the user of the electrodes has the advice of a competent metallurgist, the advice of reputed electrode makers and, particularly, of the manufacturer of the steel should be taken on the characteristics of the steel and the suitable electrode. Some of the important characteristics of a few of these and similar alloys are given below as a general guide. Metallic arc welding is presumed.

(1) 3 *to* 3·5 *per cent nickel alloy steel* tends to air harden. If the carbon content does not exceed 0·25 per cent a slow cooling welding procedure will avoid excessive embrittlement. Preheating to 150° to 300° C. is recommended for carbon contents above the limit quoted, but after an initial preheat at the starting point of the weld it may be found possible to keep up the temperature by the welding method.

(2) *With* 1 *to* 2 *per cent nickel with* 1 *to* 1·6 *per cent copper*, carbon less than 0·25 per cent, and

(3) 0·6 *to* 1·6 *per cent manganese with* 0·3 *to* 0·7 *per cent molybdenum*, carbon less than 0·25 per cent, preheating is necessary to about 150° C. if carbon exceeds 0·2 per cent and in all thick plates and sections. Slow cooling always advisable.

(4) When molybdenum rises above the limit given (towards a new limit of 1·0 per cent, the manganese content is usually less than 0·6 per cent; in this case preheating to just over 200° C. may be advisable.

(5) *With* 1·0 *to* 3·5 *per cent nickel*, 0·4 *to* 1·75 *per cent chromium*, carbon 0·2 to 0·55 per cent, lower chromium and carbon contents demand slow cooling, and preheating soon becomes necessary, from 150° C. up to 650° C. depending on alloy content.

(6) *With* 0·5 *to* 1·1 *per cent chromium*, 0·15 *to* 0·25 *per cent molybdenum*, 0·25 to 0·55 per cent carbon, preheat from 150° to 450° C., as the alloy content increases, with suitable high rate of heat input during welding always a possibly mitigating medium.

(7) *With* 0·6 *per cent to* 1·10 *per cent chromium*, maximum 0·55 per cent carbon, and

(8) 1·6 *to* 1·9 *per cent manganese,* 0·25 to 0·55 per cent carbon, roughly same as (6).

In summary, the effects of increasing carbon and chromium content, alone or in combination, are likely to require early and increasing preheat, molybdenum is less effective in this way, manganese under 1·5 per cent is not very troublesome, and nickel even less so. This is at least a broad view of the alloy content effect in this low alloy range of steels from the practical welder's standpoint. When an expert is available, he should be consulted, and when he is not available it is advisable to keep to the safe edge of the range of precautions suggested above.

It may also be noted that authoritative opinion on the welding of these steels recommends that the limit of carbon content should be about 0·15 per cent, and that the limit of tensile strength should be about 38 to 40 tons per square inch. This does not mean that stronger steels with higher carbon content cannot be welded, but it will be found that manufacturers and knowledgeable users of these alloys favour such limits where possible, because they facilitate economy and efficiency in welding with a minimum of preheating.

An entirely different class of alloys is the **stainless iron group** which contains 12 *to* 28 *per cent of chromium.* In welding, these tend to form a coarse grain. The maker of the alloy will advise on its welding, and the choice of a suitable electrode will mitigate grain growth in the weld metal. The carbon content must be kept low (usually less than 0·1 per cent); chromium is lost during welding and has to be made up by excess in the electrode core or the coating. To obtain satisfactory weldings in 15 per cent to 18 per cent chromium iron, the finished article should be suitably treated by heating to close on 800° C., followed by slow cooling, when the best possible mechanical and corrosion resistant properties will be secured.

A group of alloys of which the uses have grown rapidly over the past ten years, called the **stainless steels,** are welded with comparative ease. The most popular alloy content is 18 per cent chromium, 8 per cent nickel, and the carbon content is kept below 0·1 per cent. Other alloys in the group have contents of 25 to 12 per cent and 25 to 20 per cent chromium to nickel. The manufacturers have developed a weldable series of these alloys and it is important that these should be used. Otherwise it will be found that the corrosion resistance of the weld tends to be considerably reduced by what is called carbide precipitation at the grain boundaries; the effect of this corrosive attack has been described as a decomposition of the carbides round the boundaries until the grains become detached. Formation of the carbide is inhibited in the weldable alloys by the addition of stabilizing elements such as titanium; also the carbon content is kept low whether the stabilized or unstabilized alloys are being used.

In contrast to mild steel the properties of this group of metals (which are austenitic) are obtained by rapid cooling, so that the welding should be by small runs and the job should be kept cool. As the thermal conductivity is low (in 18-8 it is only one-quarter that of mild steel), additional care should be taken on this account against the gathering of heat around the weld. Further, these austenitic steels are very susceptible to grain growth and overheating should be avoided for this reason.

The welding contraction (based on the thermal expansion coefficient) in the stainless steels is about 50 per cent greater than that in mild steel, and the fact that a given joint in stainless steel will require more runs of weld than the equivalent joint in mild steel multiplies the contraction effect and makes jigs and contraction allowances of great importance in many cases.

As in the stainless irons, loss of chromium during welding is made up by excess chromium in the core or coating of the electrode.

The metal is strong and ductile, so that little danger from residual stresses need be feared. In machining it is important that the tool is not allowed to chatter, because the metal tends to work-hardening and soon becomes practically unmachinable; with steady close contact, the tool will, on the other hand, cut quite freely. Hammering also hardens the material, a point to be borne in mind.

Austenitic manganese steel with 12–14 per cent manganese depends for its properties on quite drastic quenching from high temperatures (over 1000° C.). It is therefore difficult to weld because the weld disturbs the parent metal in the junction, heating a band of metal to temperatures at which its properties are lost and cannot be recovered without the quenching treatment just referred to. A nickel content of 3–5 per cent and comparatively low carbon is recommended in the electrode core or welding rod, and another recommendation is to use an 18-8 stainless steel electrode. At best the weld is probably only of 50 per cent strength value. Small runs and avoidance of overheating are essential.

COPPER

Copper may be welded readily if simple precautions are taken. From the welding point of view, there are two kinds of copper, the difference between them being in the oxygen content in the metal. The oxygen content of commercial copper may be about 0·03 to 0·04 per cent, and the effects of oxygen content are to form a cuprous oxide that forms weak planes at the grain boundaries, and tends to cause embrittlement of the metal due to the absorption of reducing gases if present (as in the oxy-acetylene flame). Deoxidized or oxygen-free copper is therefore used whenever possible for weldings; otherwise the weld is weak. In choosing the metal for filler rods and electrodes, the purpose of the welded part must also be considered; if electrical conductivity is required the deoxidizer in the metal or rod must not reduce this property, but if high strength and ductility are the only considerations all deoxidized coppers may be satisfactory.

The principal difficulty in welding copper is its high thermal conductivity. The heat supplied by the arc or the gas flame must be so great as to replace the heat dispersed rapidly by conduction, this in addition to the heat required for melting the metal. The melting temperature of the metal is also moderately high, 1083° C. It is sometimes necessary to preheat the part before welding, and it is often advisable to insulate the job from loss of heat to the work bench or by radiation, leaving only the weld exposed.

In oxy-acetylene welding, the flame must be large, and the weld should be hot forged or cold peened if full strength is required. The arc methods supply greater heat, and the carbon arc using a long high-voltage arc usually makes good welds comparatively easily; the filler rod may, in this case, be phosphor bronze or silicon copper.

Bronze welding has also been successfully applied in several special applications.

ALLOYS OF COPPER

It is impossible in the scope of this section to collect welding data on all the alloys of copper that may be presented for welding, but brief notes on brasses and bronzes may be useful. The alloys concerned are of copper with zinc, with tin, and with tin and lead. Their mechanical properties depend on the alloy content and care has to be taken that any changes in chemical properties due to welding are recognized and allowed for.

Alloys containing zinc are susceptible during welding to loss of zinc, and therefore to loss of some of the properties of the alloy, because the boiling point of zinc is 905° C. and the melting temperature of such alloys varies between about 900° and less than 1000° C., so that vaporization occurs immediately the metal reaches the liquid state. Control of vaporization of zinc during welding is by keeping down the temperature of the molten metal and by playing a strongly oxidizing flame across the molten surface to form a protective oxide film, and in arc welding (with the carbon arc) by keeping the bronze below melting temperature while zinc-free metal is melted into the weld groove; in the latter case, the superheated filler metal effects fusion with the parent metal.

The thermal conductivity of brasses and bronzes is much lower than that of copper (although higher than steel) so that the heat lost in this way is relatively never serious. Rapid cooling is not harmful and is often desirable.

Tin and lead oxides tend to form in welding phosphor bronze, essentially an alloy of tin and zinc, usually also with an appreciable content of lead. The control is by using filler metal containing sufficient phosphorus to secure deoxidation. Also the band of heated metal should be kept narrow, and cooling should not be too slow; otherwise cracks and porosity are apt to form in the weld junction and the heat affected metal. Arc welding by carbon arc and by metallic arc coated electrodes are suitable processes.

For protection from air and other gases, and to clear oxides, a flux of borax diluted with boracic acid or sodium carbonate is recommended, but certain special well-tested fluxes are obtainable under trade names.

The inclusion of silicon and aluminium as deoxidizers in copper-lead-tin phosphor bronze is avoided; even small contents may make these metals thoroughly unsound. On the other hand, both these metals form straight alloys of good quality with copper, and the alloys can be welded.

ALUMINIUM

Commercially pure aluminium can be welded readily by gas and arc welding. There is always an oxide film on the surface of aluminium, this film forming a protection against further oxidation; immediately it is broken by any means, mechanical or chemical, the scale reforms. The film is therefore invaluable as it transforms a metal that readily combines with oxygen to form this oxide into a corrosion resistant metal; but this film must be deliberately removed in the welding process or no fusion will take place. It is most successfully removed by a suitable flux.

When using oxy-acetylene, a neutral flame is best. The gas pressures in the torch and the size of the nozzle tip should be determined by test and the recommendations of the makers. The oxy-hydrogen flame should also be balanced, i.e., the gas volumes should be equal at the nozzle tip. In both gas welding processes the flux is applied to the job by brush, but the flux is coated on the metal electrode for metallic arc welding. The metal core in the metallic arc electrode is quite usually aluminium-silicon (silicon 5 per cent) but for maximum corrosion resistance pure metal is best.

In aluminium alloys with magnesium and chromium, magnesium and manganese, silicon and magnesium and some other alloys, many of which obtain their highest strength by heat treatment, the stresses caused by weld contraction may result in serious cracks. Generally, single run welds and narrow welds by metallic arc and carbon arc keep this difficulty under control.

GENERAL CONCLUSION

The steels that are used in most large structures such as bridges and ships are very easily welded, and all welds in these steels should be sound and weld failures very rare. These steels constitute by far the greater part of all metals used and welding is therefore applicable to the preponderant portion of the vast field of metal construction. Also a great many of the other metals are welded with ease, although a certain number of metals call for knowledge and care. Only a relatively small number are really difficult to weld; the principal recommendation we have to offer to welders and their supervisors, and to draughtsmen and technical engineers, is that the difficulties should be appreciated and that no weld on any metal the characteristics of which are unknown should ever be sold to a customer. Care should always be taken to obtain expert advice, when any new problem arises, from the many sources of knowledge on welding and metals now available.

The notes given above indicate only a few of the alloys on which welding is practised and omit many popular and useful weldable metals; the main purpose of the selection is to indicate tendencies for the sake of the reader who has not studied metallurgy.

APPENDIX

SAFETY PRECAUTIONS AND REGULATIONS FOR FULL PARTICULARS SEE MEMORANDUM

THE Home Office issue a "Memorandum on Electric Arc Welding (1937)" published by H.M. Stationery Office at 3d. This gives an exhaustive survey of the possible dangers and recommends various precautions.

It is first pointed out that the welding process is exempted from the Electricity Regulations of the Factory and Workshop Acts, provided it is worked in a safe manner. The occupier is responsible for the necessary safety provisions and the workman or welder is also responsible for using the safeguards provided.

A summary of the recommendations and observations (they are not regulations) is as follows—

1. In hazardous situations D.C. is to be preferred to A.C. since at equal open circuit voltages the danger of serious shock is greater with A.C. In addition the open circuit pressure of the average D.C. welding supply is 70 volts, whereas with A.C. it is about 85.

2. With A.C.—

(*a*) The O.C. voltage should not exceed 120.

(*b*) Transformers should be double-wound.

(*c*) One pole of the welding supply should be earthed.

(*d*) The risk of a dangerous shock depends very much on whether the welder is insulated from earth. For example, whether the ground is wet or dry.

(*e*) The electrode holder should be insulated so that live parts cannot easily be touched. Leather or asbestos gloves are not insulators.

(*f*) Where the floor is not of dry wood or insulated the welder should wear insulating boots, e.g. of rubber.

(*g*) A switch should be provided in the welding lead for cutting off the current when changing electrodes.

(*h*) The cable should be well insulated and in good repair particularly where it is attached to the electrode holder.

(*i*) All live parts should be protected and switch, resistance and reactance covers, etc., should be earthed.

3. With D.C. even at 100 volts, the risk of a dangerous shock is very small. Nevertheless some of the above provisions for A.C. are desirable, particularly an insulated holder.

4. Reactance in the circuit causes a momentary rise in voltage at the holder when the arc is broken.

5. Main supply system. The main supply pressure for portable sets should be "medium" and cables highly insulated and protected. A switch should be provided on the set and the frame earthed through a wire in the supply cable.

6. Special risks occur in ship construction or repair, erection work and in boiler repair work. In such cases the supply should be D.C. at an O.C. pressure not exceeding 60 volts.

7. Radiation effects. The symptoms of "arc-eye" are described and covering the eyes with a cloth damped with cold water suggested as a relief. B.S.S. No. 679, 1936 "Protective Glass for Welding and Other Industrial Operations" is quoted. The radiation from the arc may be divided into—

(*a*) Infra-red radiation causing heating and possibly cataract.

(*b*) Visible light radiation.

(*c*) Ultra-violet radiation causing "arc-eye."

The specification lays down limits for the maximum permissible transmission of (*a*) and (*c*) above. The colour of a glass is of secondary importance, but an apparently dark glass may not be safe.

The welding grades for glasses are—

For metal arc up to 75 amps., Grade C.

For metal arc over 75 amps., Grade D.

For carbon arc welding and cutting (also probably metal arc over 250 amps.), Grade E.

A practically clear glass, known as Crookes' spectacle glass, absorbs all of the dangerous ultra-violet light and is useful for those working near welders.

The hand screen or helmet should be of insulating material and affords ample protection.

Gloves and aprons should be of non-ignitable material.

8. The danger of hot metal and slag particle is mentioned. Fumes should be removed from confined spaces by means of fans, compressed air or both. In particular, zinc fumes, for example from galvanized iron, produce most unpleasant after-effects.

A few comments on this memorandum are—

1. The recommendations 2 (*e*), 2 (*f*), 2 (*g*), and, in part, 2 (*i*) above, are not necessary for O.C. pressures up to 90 volts *except* when special risks are present. For example, when the welder's clothing is damp from sweat or rain and he is working touching or standing on metal or on a damp floor; or when welding is being carried on in positions where a slight shock might cause the welder to fall.

2. The three grades of dark glasses C, D, E when supplied from one maker may not give a fine enough variation of density to suit every welder. It may be found that the same grades from another maker will be of slightly different densities.

3. The suggested use of plain Crookes' glass spectacles for welders or for those working near is very sound.

NOTE.—O.C. Open Circuit.

[*Author's Comment:* Although the recommendations of this memorandum may in practice be deemed ultra-safe, the memorandum should be studied by all persons of authority using welders, because the dangers to which attention is called and the recommended precautions should always be in mind in using the process.]

INDEX TO VOLUME V

INDEX

The items in this index are grouped together in sections
The numbers refer to pages

SECTION XX

DROP AND MACHINE FORGING

Air clutch, 37, 40
"Ajax" forging press, 37
Alloy steels for dies, 47
Anvil, 5
—— block, 27
—— face, 28
Atritor pulverizer, 68

Balancing dies, 50 51
Baulks, timber, 27
Belts, 5-7
Bending stock, 56 59
Blacksmith's spring swage, 3
Board hammer, 17
—— ——, four roll, 21 24
Brass stampings, 73
"Brett" friction lifter, 9, 10
—— steam lifter, 7
Buckles, 33

Carbon steel for dies, 47
Catch, swinging, 5
"Chambersburg" steam drop hammer, 24
Circular die blocks, 48
Cleaning, 73
Clutch, air, 37, 40
—— ——, friction, 10, 12
Crane, overhead travelling, 75
Cutting dies, 48–49

Dies, 5, 28, 35–36, 39, 43, 45–53
——, cutting, 48–49
——, multiple impression, 43, 51
Drive, motor, 19, 40
Drop stamp, 5
—— ——, automatic friction, 12
—— ——, board, 17
—— ——, steam, 7
Dummying stock, 51–52, 54

Equipment, general, 74
"Erie" roll hammer, 21
Extrusion, 40

Fin, 34, 53–55
——, removing, 71
Flash, 39, 45, 53-55, 59, 71
Folds, 33
Forging machine, 29–32
—— press, 37
Forgings, quality of, 29 37
Forked stampings, 59 60
Foundations, 27
Friction lifter, 9–16
Furnaces, 60–70

Gas-fired furnace, 61
Gear, "Simplex," 14
Grain flow, 34, 58
Guides, tup, 5, 28

Heading machine, 29-32
Heat-treatment department, 73
Heating, 35, 45, 60

Kicking step, 50

Lay-out of die shop, 53
—— of forge shop, 75
Lift, power, 5
Lifter, friction, 9–16
——, steam, 8
Luminous flame furnace, 61

"MASSEY" friction lifter, 12
—— guided ram hammer, 24
Multiple impression dies, 43, 51

"NATIONAL" forging machine, 30

OIL-FIRED furnace, 64
Oliver, 3, 4

POWER lift, 5
Preheater, electric oil, 67
Principle of drop forging, 3
Pulverized coal furnace, 67

QUALITY of forgings, 29–37

REAR-EXTENSION guided slide, 39–41
Revergen furnace, 62
Rhythm, 44

SHOP methods, 43–45
——, lay-out of die, 53
——, —— of forge, 75
Side sprue cutter, 71
Size of stock, 55
Stampings, long and thin, 56
Steam drop stamps, 7
—— hammers, 24
—— lifter, 8
—— valve gear, 8
Steel, choice of, for dies, 35, 45–48
Stock, bending, 56–59
——, dummying, 51–52, 54
——, heating, 60
——, size of, 55
Stoving-up machine, 31
Straps, 5–7, 9
Stroke control, variable, 23
Swage, spring, blacksmith's, 3
Swinging catch, 5

TEAM work, 44
Timber baulks, 27
Trimming press, 71
Tup guides, 5, 28

UPSETTING, 29

VALVE gear, 8, 24

SECTION XXI

DIE-MAKING, PRESS WORK AND STAMPING

ADVERTISEMENTS, metal, embossed, 153
Assembly, final, 89, 105, 145
—— tool, 150

BASE plate, 107, 129
Bending and forming, 96–100
—— tool, spring pad, 92
—— ——, "V," 82, 84
Blank sizes, determining, 91
—— tool with spring stripper, 106
Blanking and piercing tool, 85–86, 100, 114
—— die, 130
—— formed fittings, 118
—— punch, 145
Blue prints, 82
Bolster, 92, 101, 113, 127, 128
Built-up die, 115
Bush piercing, 141

CALIPERS, 82, 129
Candle shade holder, 124
Canopies, stove, 152
Casing, outside, 109
Combination tool, 138
Countersink, 95
Crop and piercing tool, 91

"D" BIT, 88, 94, 95, 107
Die, built-up, 115
——, embossing, 140
—— housing, 116, 142

Die, lay-out of, 102, 113–115
——, marking off, 86
Dies, sectional, 115
Domestic bowls and basins, 152
Draw plate tool, 122
Drift, 96
Drilling machine, uses for, 124

EMBOSSING die, 140
—— punch, 143
End stop pins, 111
Equipment, tool-maker's, 81–82

FILING, 88
Final assembly, 89, 105, 145
Follow-on tool, 100, 116
Formed fittings, blanking, 118
Forming tools, 148

GAUGE, height, 81
——, profile, 102
Gauges, male and female, 127
Guide posts, 105, 111, 121
Guillotine, hand, 134

HOUSING, die, 116, 142
——, spring and punch, 144

LARGE tools, 152
Lay-out, alternative methods of, 89
——, follow-on tool, 116
—— of die, 102, 113–115

MACHINING "V" groove, 82
Marking off die, 86
Micrometers, 81, 140, 147
Morse taper reamer, 88

OPEN dies with spring stripper, 120
Outside casing, 109

PIERCING bush, 141
—— tools, 130–132
Pin cutters, 94, 95
Precision instruments, 18
Punches, 84, 89, 103, 105, 107, 111, 127, 130, 134, 143, 145, 153

REGISTER pins, 89, 111, 121
—— plates, 82, 84, 85, 91–92
Return tool, 112, 113
Rose cutter, 96

SECTIONAL dies, 115
Side-piercing tool, 118
—— plates, 92
—— stop, 103
Special tools, 94–96
Spigot and spigot plates, 84, 85, 89, 101, 105, 130
Spring clip, 135
—— forming tool, 126
—— pad, 110, 128, 142
—— —— bending tool, 85, 92
—— stripper, 109, 129
—— strippers, open dies with, 120
Square, tool-maker's, 96
Steel, quality of, 80
Stove canopies, 152
Stripper plate, 89, 104
——, spring, 109, 120, 129
Surface plate, 86

TAPER reamer, 94, 107
Toggle press, 125
Tool-maker's equipment, 81–82
—— square, 96
Training, 80
Turn-over tool, 111, 114

"V" BENDING tool, 82, 84
—— groove, machining, 82
Verniers, 81, 140, 147

WHEEL, toy train, production of, 137
Workshop, introduction to, 80

SECTION XXII

PRACTICAL BLACKSMITHING

ADJUSTABLE work stand, 171, 172
Angle iron, bending and welding, 214
Annealing, 185
Anvil, 169
Appliances, 159

BELLOWS, 164
Bending, 193, 214
Blacksmith's hand hammer, 173
Blast, 164
Blowers, 167
Bosh, water, 161
Bottom swages, 185
Breeze, smithy, 168
Bulb twist, 226
Butt joint, 206

CALCINED borax, 193
Case-hardening, 186
Chimneyless hearth, 163
"Climax" forge, 160
Cold sate, 175
Composite simple former, 214
Crimping, 225

DOUBLE strap hinge, 199
Drawing and blacksmithing, 158
—— and tapering, 187
Drifts, 177
Duplex blowing fan, 165

EYES, forging, 208

FIRE, lighting, 168
Flatter, 176, 183
Fluxes, 193
Forge, 159
Forging eyes, 208
—— smith's tools, 179
Fork ends, 211
Fuel, 168
Fullering hammer head, 180
Fullers, 178, 184

GOUGE, 176
Grain, effect of tools on, 196

HAMMERS, types of, 172
——, forging, 179
——, power, 219
Hardening, 185
Hardie, 176
Hearth, 159
Hinges, various forms of, forging, 199
Hot sate, 176, 198

IMPORTANCE of the blacksmith, 157
Iron hearth, 160
Ironwork, ornamental, 222

JUMP weld, 192
Jumping, 188

LAP scarf, 191
Letting-down, 186
Levelling plate, 171

MACHINE hammers, 219
Mandrel, smith's, 171
Middle Ages, blacksmithing in, 157
"Mota" forge fan, 167

NEUTRAL line, 206

OPEN-MOUTH tongs, forging, 181
Ornamental ironwork, 222

PNEUMATIC forging hammer, 219
Power hammers, 219
Prussiate of potash, 187
Punches, 177, 198

REPETITION work, 189
Right angle bends, 194
Ring methods of determining length of material, 204
Roots blower, 167

SATE, 175, 176
Scarfing, 190
Scrolls, 223
Set hammers, 184
Sledge hammer, 173
Smithy, importance of, 157
—— of old days, 157
Solid eyes, 210
South Kensington Museum, 228
Square joint in angle iron, 214
Steam hammers, 219
Strap hinge, forging, 201
Swage block, 170
Swages, 179, 184, 185

TAPERING bar iron, 187
Tee weld, 191
Tempering, 185
Tongs, 174, 181
Top swages, 184
Traveller, 208
Tee-iron sections, 162

UPSETTING, 188

VEE scarf, 191
Vice, 171

WATER bosh, 161
Welding, 192, 214
—— of scrolls, 234
Work rests, 172
Work stand, adjustable, 171, 172

SECTION XXIII

WELDING

ABSORPTION of gases, 238
Acetylene, 298 303
– generators, 300 303
-——, storage of, 299
Air-acetylene flame, 311
Alternating current, 261 263
Aluminium welding, 334
Amperage, 246
Arc length, 246, 249, 267
—— welding, 231, 234, 245, 286
Atomic hydrogen welding, 234, 292

BLOWPIPE, 307
Bronze welding, 320–323
"Burning," 236
Butt joints, 232, 267, 271, 272, 274, 310

CABLES, welding, 263
Capital costs, 259, 263
Carbon arc welding, 234, 286–292
Carbonizing flame, 305, 306
Cast iron, cutting, 319
— – — —, welding, 326
Castings, welding, 280
Chilling, 241, 243, 324, 325
Circuit, welder's, 245, 289
, , faults in, 264
Clothing, protective, 250
Copper, solubility of oxygen in, 239
--, welding, 331
Current values, 251, 261, 262, 268, 269, 272
Cutting flame, 314
– , gas, 282, 313-319
machines, 315

DIRECT current, 261 263
"Dissolved" acetylene, 299
Distortion, 241-242, 319
Downhand positions, 269
"Drooping characteristic" machines, 254, 259

ELECTRIC arc, 245
Electricity supply, 255, 261
Electrodes, 245, 246, 249, 267, 289, 292
Equipment, welder's, 250
Eyes, protection for, 250, 338

FILLET joints, 267, 273, 275, 310
Flame, cutting, 314

Flame, welding, 303–307, 311
Fluxes, protecting, 239, 241, 244, 289, 322, 333
Forge welding, 231
Fusion processes, 232
—— ——, problems in, 236

Gas cutting, 282, 313–319
—— quantities, variation of, 306
—— solubility, 238
—— welding, 231, 234, 295
Generators, 252–255, 259, 291, 300
Grain size, 236

Heating, 232–235, 241, 303
High carbon steels, 326
—— pressure acetylene, 299
—— —— cutter, 314
—— —— plant lay-out, 307
Home Office Memoranda, 262, 297, 302, 337–339
Hydrogen, solubility of, in steel, 238

Impurities in steel, 240
Irons, cast, cutting, 319
——, welding, 323, 329

Jigs, use of, 285
Joints, arc, 265–267
——, butt, 232, 267, 271, 272, 274, 310
——, fillet, 267, 273, 275, 310
——, oxy-acetylene, 310–311

"Leftward" welding, 311
Low carbon irons, welding, 323
—— —— steels, welding, 324
—— pressure acetylene, 300
—— —— plant lay-out, 308

Machines, gas cutting, 315
——, welding, 251–261
Magnetic disturbance of arc, 262
Medium carbon steels, welding, 325

Metallic arc welding, 245
—— —— ——, applications of, 276
Multi-operator generators, 254, 259
—— transformers, 257

Neutral flame, 305, 306

Overhead positions, 270
Overheating, 236
Oxidation, 235, 237, 313
Oxidizing flame, 305, 306
Oxy-acetylene flame, 304
—— welding, 238, 295
Oxy-hydrogen welding, 295, 311
Oxygen, 296–298
——, solubility of, in metals, 238
——, storage of, 297

Phosphor bronze welding, 333
Plant, gas cutting, 315
—— lay-out, 307, 308
——, welding, capital costs of, 259, 263
Plastic processes, 232
Plate work, welded, 282
Polarity of arc, 247, 267, 289
Porosity, 239, 267
Positions, welding, 269
Pressure vessel welding, 276
Protective clothing, 250

Resistance welding, 234, 235, 237
"Rightward" welding, 311
Riveted *v.* welded construction, 278
Rusting, 235, 237

Scale, 235, 237, 314
Scarf joint, 232
Short circuits, 264
Slag, 238, 239, 240, 244, 267
Smith welding, 231, 235
Stainless iron, welding, 329
—— steel, welding, 330
Steels, gas cutting, 319
——, various, welding, 324–326, 327–331

Stresses, 239, 243, 319, 325
"Striking" voltage, 252, 254, 255, 261
Structural welding, 282

TEMPERATURES, 231, 232-235, 241, 303
Thermit fusion welding, 320
Time factor, 260
Tools, welder's, 250
Torch, cutting, 314
——, welder's, 307, 310
Transformers, 255, 259

"V" JOINT, 232
Vertical positions, 270

WELDED *v.* riveted construction, 288
Welding processes, characteristics of, 233
— — ——, success of modern, 244
Working voltage, 251
Wrought iron, welding, 323